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CONTROL OF VOLATILE ORGANIC EMISSIONS FROM EXISTING STATIONARY SOURCES - VOLUME II: SURFACE COATING OF CANS, COILS, PAPER, FABRICS, AUTOMOBILES, AND LIGHT-DUTY TRUCKS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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This report provides the necessary guidance for development of regulations to limit emissions of volatile organic sources (VOC) of hydrocarbons, especially from the coating operations of five industries: can, coil, paper, fabric and automobile and light duty trucks. This guidance includes an emission limit which represents Reasonably Available Control Technology (RACT) for each of the five, analytical techniques for determining the solvent content of coatings, EPA's policy on the control of VOC, and a monograph on how these components can be used to develop a State regulation.

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Emission Standards and Engineering Division
Chemical and Petroleum Branch

U.S. ENVIRONMENTAL PROTECTION AGENCY
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1-A

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PREFACE

This is the second in a series of reports designed to assist State and local jurisdictions in the development of air pollution control regulations for surface coating industries. These reports are directed entirely at the control of volatile organic compounds (VOC) which contribute to the formation of photochemical oxidants. Volume I provides very general information on the cost and effectiveness of control technology and guidelines for sampling and analyzing VOC emissions.

Volume II provides specific information on air pollution control of five surface coating industries; namely, automobile and light duty truck, can, coil, fabric and paper coating operations. For each industry, coating systems are reviewed and various VOC control alternatives are considered together with their costs and limitations. This volume also provides guidance on the preparation of air pollution control regulations and test methodology suitable for their enforcement (Appendices A and C).

It must be cautioned that the limits provided below are based on capabilities and characteristics which are general and therefore presumed normal to these industries; the limits may not be applicable to every plant within an industry. For example, although the level of control recommended for the can industry is based on coatings that are generally available, those coatings may not be suitable for every product manufactured by a can plant.

In each case the recommended limitation is stated in terms of solvent content of the coating. This form is most applicable to situations where low solvent coatings are employed. If an operator should choose to comply by installation of add-on control devices, it may be appropriate for the agency to set minimal requirements on the hooding or capture system and the efficiency of the control device.

The tables that follow provide emission limitations that represent the presumptive norm that can be achieved through the application of reasonably available control technology (RACT). Reasonably available control technology is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical, source categories. It is not intended that extensive research and development be conducted before a given control technology can be applied to the source. This does not, however, preclude requiring a short-term evaluation program to permit the application of a given technology to a particular source. This latter effort is an appropriate technology-forcing aspect of RACT.

CAN INDUSTRY

Affected Facility	Recommended Limitation	
	kg per liter of coating (minus water)	lbs per gal of coating (minus water)
Sheet basecoat (exterior and interior) and overvarnish; two-piece can exterior (basecoat and overvarnish)	0.34	2.8
Two and three-piece can interior body spray, two-piece can exterior end (spray or roll coat)	0.51	4.2
Three-piece can side-seam spray	0.66	5.5
End sealing compound	0.44	3.7

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The limitation for the sheet basecoat (exterior and interior) and overvarnish; two-piece can exterior (basecoat and overvarnish) assumes the average solids content of all coatings is about 25 volume percent and the solvent is an 80 percent water, 20 percent organic mixture. The organic borne equivalent is 64 volume percent solids. Such coatings are now used by some companies on part of their production.

The limitation for two and three-piece can interior body spray, two-piece can exterior end (spray or roll coat) presumes all coatings average 18 volume percent solids in an 70:30 water to organic solvent ratio. Such coatings are now used on some beer and beverage cans.

The limitations for the three-piece can side-seam spray assumes an increase in the solids content of typical present-day coatings by 100 percent to 25 volume percent. Water-borne coatings for some unique products have been developed that are applied at solvent contents as low as 0.53 kilograms per liter of coating.

The limitation on end sealing compound emissions presumes an increase in the solids content of a typical organic-borne coating from 30 to 50 percent. Water-borne coatings for some unique products are applied at solvent contents as low as 0.26 kilograms per liter of coating.

COIL COATING INDUSTRY

Affected Facility	Recommended Limitation	
	kg per liter of coating (minus water)	lbs per gal of coating (minus water)
Prime and topcoat or single coat operation	0.31	2.6

This limitation is based on incineration of the emissions from an organic-borne coating which contains 25 volume percent solids. To comply, 90 percent of the solvent in the coating would have to be captured and directed to the control device (afterburner) which must be at least 90 percent efficient. There are also some water-borne coatings that will comply with this level of control without the need for add-on control equipment.

FABRIC COATING

Affected Facility	Recommended Limitation	
	kg per liter of coating (minus water)	lbs per gal of coating (minus water)
Fabric coating line	0.35	2.9
Vinyl coating line	0.45	3.8

"Fabric coating" includes all types of coatings applied to fabric, a large portion of which is rubber used for rainwear, tents and industrial purposes such as gaskets and diaphrams. "Vinyl coating" refers to any printing or decorative or protective topcoat applied over vinyl coated fabric or vinyl sheets. It does not include the application of vinyl plastisol to the fabric (emissions from the application of plastisol are near zero).

The limitations for both are based on use of an add-on control device which recovers or destroys 81 percent of the VOC introduced in the coating. Typically, this will require that 90 percent of the VOC is captured and delivered to the control device which also must have an efficiency of 90 percent.

The limitation for fabric coating could also be achieved by use of an organic-borne coating which is about 60 volume percent solids or a water-borne 80:20 coating with a solids content of about 24 volume percent. Neither of these coatings are known to be in routine use by the industry.

PAPER COATING

Affected Facility	Recommended Limitation kg per liter of coating (minus water)	Recommended Limitation lbs per gal of coating (minus water)
Coating line	0.35	2.9

These levels are for all coatings put on paper, pressure sensitive tapes regardless of substrate (including paper, fabric or plastic film) and related web coating processes on plastic film such as typewriter ribbons, photographic film, and magnetic tape. Also included are decorative coatings on metal foil such as gift wrap and packaging. These limits can be achieved in all cases using incineration and in many cases with coatings that contain low fractions of organic solvents.

AUTOMOTIVE AND LIGHT DUTY TRUCK ASSEMBLY PLANTS

Affected Facility	Recommended Limitation kg per liter of coating (minus water)	Recommended Limitation lbs per gal of coating (minus water)
Prime application, flashoff area and oven	0. 23	1.9
Topcoat application, flashoff area and oven	0.34	2.8
Final repair application, flashoff area and oven	0.58	4.8

These limits apply to all objects surface coated in the plant including the body, fenders, chassis, small parts, wheels, sound deadners, etc. It does not apply to adhesives.

The level recommended for prime application is based on use of an electrophoretic system followed by a 25 percent solids water-borne "surfacer" to build thickness and improve the adhesion of the topcoat. Water-borne surfacer is in use at two U.S. plants. The electrophoretic system is now in use at about half of the plants in the United States. Although several of these were converted to electrophoretic, such a transition may not be reasonable for an existing assembly line which uses a water-borne dip prime coating system releasing about 0.38 kilograms per liter of coating. The moderate reduction in emissions possible with electrophoretic coatings would be obtained at great expense.

The level for topcoat represents a water-borne coating now in use by two plants in the United States. Because of: (1) the large expenditures required to convert from organic-borne coatings to water-borne coating, it may be reasonable to grant some finite period for a source to develop low solvent organic-borne coatings with equivalent emission characteristics.

The level for "final repair" is based on use of an organic-borne enamel with 35 percent solids. Water-borne coatings cannot be employed for the assembled automobile. None of the automakers are using coatings of 35 percent solids at present but such use is now scheduled at one U.S. plant.

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1.0 INTRODUCTION

The industries reviewed herein represent some of the largest and most widespread sources of volatile organic solvents in the nation. Moreover, their products, often with very specialized surface coatings, are interwoven into many facets of our economy and are subject to a wide range of performance demands. Collectively, they release about 850,000 tons of VOC annually to the atmosphere with the largest individual sources each being responsible for over 1,000 tons per year. The five industries employ a variety of coating application and curing techniques, all of which impact on the viability of alternative VOC control technologies. From the air pollution control standpoint, it is immaterial whether VOC are removed from the coating process or are controlled at the point of emission. Nonetheless, since solvent recovery and/or elimination strongly influence control costs and acceptance by the affected industries, much of this document is directed at the review of alternative control strategies, costs, and energy impacts.

To varying degrees, four different abatement methods have been used to reduce the contribution of surface coating VOC to the photochemical oxidant burden. These are:

(1) "Add-on" technology to destroy or recover VOC from exhaust gases,

(2) Reformulation of coatings to minimize organic solvent content,

(3) Modification of the process to reduce the quantity of VOC which escapes from a coating line, and

(4) Substitution of less photochemically reactive solvents in surface coating formulations.

The first three are "positive reduction" techniques in that they actually reduce the mass of VOC released to the atmosphere. The fourth, solvent substitution, doesn't reduce the quantity of organic emissions and has been only marginally effective in reducing ambient concentrations of photochemical oxidants (see Appendix B). In preparing this document, principal attention has been directed at add-on control technology and the reformulation of coatings. These two positive reduction techniques currently offer greater potential for reducing organic emissions than process modifications for the five surface coating operations in question.

In previous years the primary method used to reduce organic emissions from stationary sources has been through stack gas treatment, primarily incineration. Incinerators or afterburners have evolved as the basic control technique to which the efficiency of alternative methods is often compared. Within the coating industry, however, incinerators have, for the most part, been limited to baking and curing ovens. In most instances, spray coating operations, which are much larger sources of VOC than associated ovens, have gone uncontrolled. It is for these coating sources that low-solvent coatings offer the greatest promise.

1.1 LOW-SOLVENT COATINGS

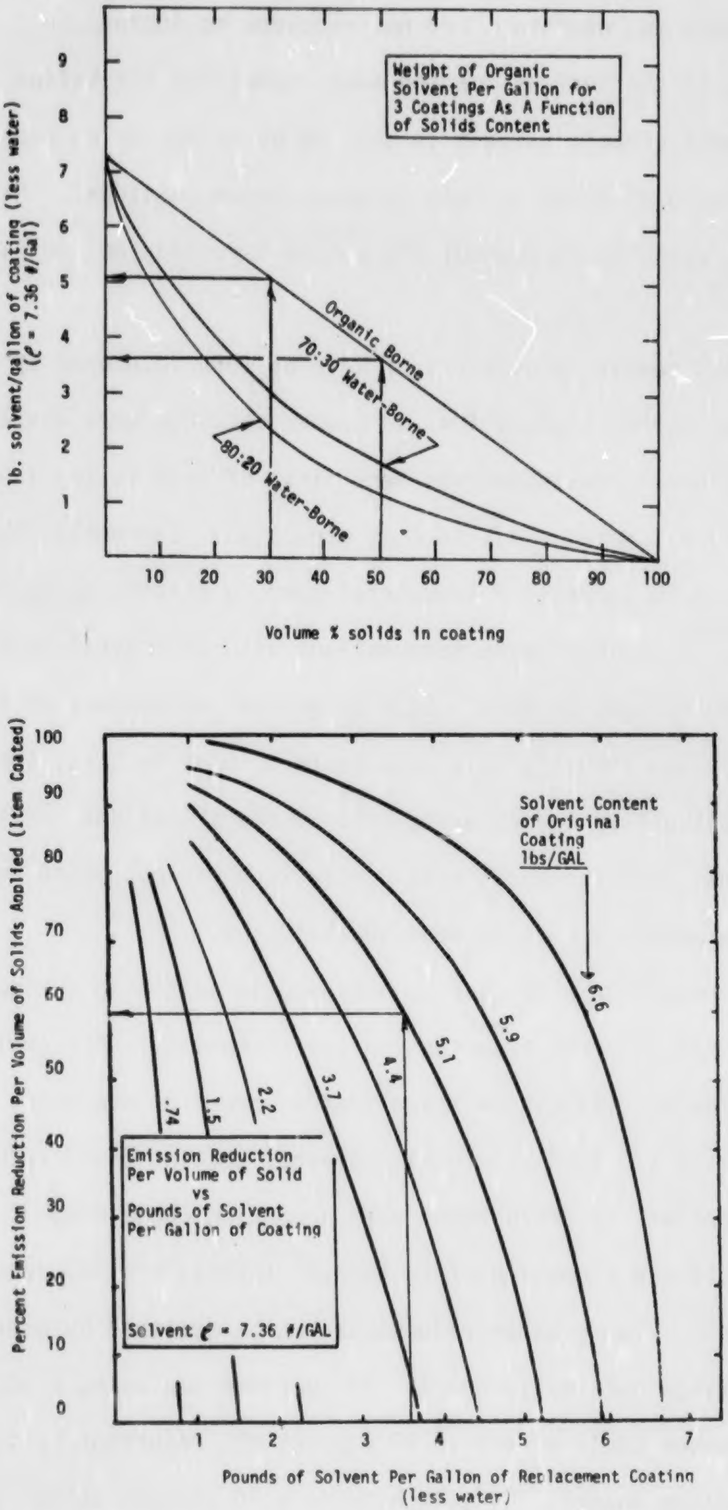
Coatings which contain relatively low fractions of organic solvent, the so-called "low-solvent coatings" (water-borne, high-solids, and powder coatings), offer the advantage of saving valuable petroleum feedstocks while also eliminating the need for abatement equipment and its concomitant requirement for fuel and power.

The desirability of low-solvent coatings was recognized and acknowledged by the Los Angeles County Air Pollution Control District in 1971 when incentives were added to Rule 66--its regulation governing use of solvents. Under Rule 66, operators are not required to incinerate oven exhaust gases if the surface coating meets specified limitations (less than 20 percent organic solvent in coating by volume or an organic solvent-to-water ratio of 20:80 or less in water-borne coatings). Many other governmental agencies throughout the nation have adopted similar incentives.

The low-solvent coating provisions of Rule 66 were developed at a time when few water-borne, high-solids, or powder coatings were available. In the six years since these incentives were first offered to the industry, there has been only a limited shift in that direction. Currently, they represent only about 10 percent of industrial surface coating sales. The rest are conventional organic-borne formulations with an organic solvent content of 60 to 90 percent or more. Lack of greater acceptance of low-solvent coatings by the industry is attributable to many factors, some of which are: difficulties in achieving Rule 66 specifications, relatively low cost of solvents, and the ability to comply with air pollution regulations by less burdensome means such as solvent substitution.

The dramatic reduction which can be achieved in switching to low-solvent coatings is often not apparent from coating specifications. For example, with the aid of Figure 1, it can be shown that an operator now using a 30 volume percent solids (70 percent organic solvent) coating could reduce his VOC emissions 57 percent by replacement with a coating containing 50 percent solids. If he could use a coating of 70 percent solids, his VOC reduction would be 82 percent. Even greater reductions can be realized by users of highly dilute coatings such as lacquers. An operator now using a 10 volume percent solids lacquer could effect an 88 percent VOC reduction by switching to a 50 percent solids enamel. By switching to a 70 percent solids coating,

FIGURE 1


Weight of Organic Solvent Per Gallon for 3 Coatings As A Function of Solids Content
lb. solvent/gallon of coating (less water)
(ρ = 7.36 #/Gal)
9
8
7
6
5
4
3
2
1
10
20
30
40
50
60
70
80
90
100
Volume % solids in coating
Organic Borne
70:30 Water-Borne
80:20 Water-Borne
Percent Emission Reduction Per Volume of Solids Applied (Item Coated)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
Pounds of Solvent Per Gallon of Replacement Coating (less water)
Solvent Content of Original Coating lbs/GAL
6.6
5.9
5.1
4.4
3.7
2.2
1.5
.74
Emission Reduction Per Volume of Solid vs Pounds of Solvent Per Gallon of Coating
Solvent ρ = 7.36 #/GAL

his VOC reduction would be 95 percent. Conversion to water-borne coatings will also significantly reduce VOC emissions. Replacement of a 30 volume percent solids organic-borne coating with an 80:20 water-borne (80 percent water, 20 percent organics) of similar solids content would yield a VOC reduction of about 80 percent for a given industrial application.

1.2 STACK GAS TREATMENT

Founding emission limitations on low-solvent technology is not without its drawbacks. In some instances, switching to low-solvent coatings may not provide as much VOC control as would add-on control devices. This could be true during any transition period as we phase into lower solvent coatings. For certain industries, it will be more effective and possibly less costly to employ incineration, adsorption, or other techniques to remove or destroy VOC in the exhaust gases. Carbon adsorption should continue to find use where the solvent has a relatively high market value and is amenable to recovery with adsorption techniques. Incineration is expected to remain a viable alternative where organic concentrations can be maintained at relatively high levels such that auxiliary fuel requirements are not excessive or where energy in the hot exhaust gases can be recovered and used to offset fuel requirements elsewhere in the plant.

A major disincentive to applying stack gas treatment to VOC sources is the low concentration of organics often encountered. These low concentrations mean large volumes of air or other diluents must be processed to control the solvent. This results in higher costs and energy requirements for control equipment and, frequently, lower control efficiencies. Major reasons for such low concentrations are: (1) solvents are toxic to the worker, hence, are intentionally diluted below the threshold limit value (TLV); (2) concentrations are maintained well below the lower explosive limit (LEL) to reduce the risk of fire or explosion; (3) large dilution ratios are necessary to accommodate fluctuations in VOC evaporation rates, and (4) the operator is unaware of the multiple benefits of minimizing the intrusion of diluent air.

The greatest dilution and lowest VOC levels are found in hand-held spraying operations and are attributable to TLV restrictions. No large worker-occupied spray booths such as those used in auto assembly plants have been controlled with VOC stack gas treatment technology. Where the coating is applied mechanically as with a knife, roller, or electrostatic spray gun, it is usually possible to maintain much greater VOC concentrations in exhaust gases. Similarly, baking and curing ovens can be maintained at VOC levels much greater than are feasible for worker-occupied spray booths.

Solvent concentrations in ovens and automated coating applications are generally maintained below 25 percent LEL because of safety hazards associated with higher concentrations.[1] Unfortunately, many ovens are operated at organic concentrations well below this level. For example, at 5 percent LEL, the exhaust rate is five-fold greater than at 25 percent LEL and any add-on control device must be five times larger. In many cases, such low concentrations are not necessary. Changes in system design and operating practices can minimize air intrusion with the attendant benefit of a reduced exhaust volume and reduced control costs.

In a few industries, operators have been notably successful in maintaining VOC levels at greater than 25 percent LEL and effecting major fuel economies. For example, several coil coaters have actually reduced fuel consumption in the coating oven by use of incineration devices and heat exchangers and maintaining VOC concentrations at 30 to 40 percent LEL. In many more applications, incineration would be a more cost effective control option if air intrusion were minimized and VOC levels held to 25 percent LEL or greater. This ancillary aspect of VOC control has received only limited attention in many industries.

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[1] Some insurers will permit operation up to 50 percent of the LEL if appropriate monitoring and fail-safe relief systems are installed.

1.3 EMISSION LIMITATIONS

Historically, VOC control regulations have included limitations on the organic solvent of coatings or have stipulated that a certain percent reduction be achieved through stack gas treatment. While either approach is acceptable if limits are appropriate, solvent content is a more reasonable basis for surface coating operations which are expected to employ low-solvent coatings.

For these five industries, it is recommended that emission limitations be expressed in terms of organic solvent content since these values can be determined with relatively simple analytical techniques and are directly relatable to VOC emissions. For operators who use stack gas treatment, alternative compliance procedures should be included.

Solvent content limitations may be expressed in terms of mass or volume and may be based on the entire coating (including solvent) or only on paint solids. In this document, limitations are expressed as the allowable mass of VOC per unit volume of coating (kg per liter or lb per gallon) as it is applied to the product. The principal advantage of this format is that enforcement is relatively simple. Field personnel can draw samples and have them analyzed quickly. A disadvantage is that the relationship between the solvent fraction and VOC emissions is not linear. As illustrated in Figure D-2 of Appendix D, use of a coating containing 3 lbs of VOC per gallon of coating emits 4.4 times as much solvent as use of one with 1 lb per gallon and only 55 percent as much as one of 4.1 lbs per gallon. Thus, VOC emission rates could be easily misunderstood by the general public.

The above disadvantage is eliminated if the solvent content is expressed in terms of mass of VOC per unit volume of paint solids (again kg per liter or lb per gallon). Here the relationship is linear and more readily understood by the public, e.g., a coating containing 2 lbs per gallon of solids releases twice as much VOC as one of 1 lb per gallon. The disadvantage of this format is that it relies on an analytical method which has had only limited usage in the industry and is virtually untried by control agencies. When more experience is developed with the procedure for measuring the volume of solids in a coating sample (approved by the American Society for Testing and Materials), it may be reasonable to express limitations in terms of paint solids. Until these uncertainties are resolved, it is recommended that limitations be based on the volume of the coating (minus water). Appendix A presents ASTM test methods for determination of the pounds of VOC per gallon of coating (minus water).

Other options such as lbs or gallons of VOC per lb of coating are generally less desirable although they may be entirely appropriate for a given industry. Basing limitations on the mass of coating or paint solids is not recommended because the specific gravity of coatings tends to vary widely with the degree and type of pigmenting employed. Highly pigmented paints have much greater density than unpigmented clear coats or varnishes. Furthermore, basing limits on paint mass might encourage users to employ a greater degree of pigmentation solely to meet air pollution limits. Mass rather than volume of VOC is recommended for emission limitations because measurement techniques are simple and because VOC mass is more closely related to photochemical oxidant formation.

For any given industry, it may be desirable to express solvent limits in terms other than those recommended in the Preface. In such instances, it will be necessary to adjust numerical limits such that they provide the desired degree of control. Appendix D provides equations and charts through which recommended limits can be translated into other solvent limitation formats.

The approach outlined above was designed for coating processes where low-solvent coatings are to be employed. In those few industries where stack gas treatment is a more likely option, it may be more appropriate to state emission limits in terms of control efficiency across the incinerator, adsorber, etc. This concept is discussed in Appendix C. Where limitations are expressed only in terms of the coating content, it will be necessary to determine mass emissions from the control system and relate them to the quantity of coatings applied during the test period. It is often difficult to determine the consumption of coatings during any given period and to ascertain the fraction of VOC which is directed to the control device. In most instances, it will be more reasonable to provide an alternative efficiency requirement for those situations where add-on control technology is used in lieu of a complying low-solvent coating.

2.0 CAN COATING

2.1 Summary of Control Technology

Affected Facility *	Control Options	Percent Reduction
Two-Piece Can Lines		
Exterior Coating:	Catalytic and non-catalytic incineration	90
	Water-Borne & High-Solids coatings	60-90
	Ultraviolet Curing	up to 100
Interior Spray Coating:	Catalytic and non-catalytic incineration	90
	Water-Borne & High-Solids coatings	60-90
	Powder Coating	100
	Carbon Adsorption	90
Three-Piece Can Lines		
Sheet Coating Lines		
Interior Coating:	Catalytic and non-catalytic incineration	90
	Water-Borne & High-Solids coatings	60-90
Exterior Coating:	Catalytic and non-catalytic incineration	90
	Water-Borne & High-Solids coatings	60-90
	Ultraviolet curing	up to 100

Can Fabricating Lines		
Side Seam Spray Coating:	Water-Borne & High-Solids coatings	60-90
	Powder (only for non-cemented seams)	100
Interior Spray Coating:	Catalytic and non-catalytic incineration	90
	Water-Borne & High-Solids coatings	60-90
	Powder (only for non-cemented seams)	100
	Carbon Adsorption	90
End Coating Line		
Sealing Compound:	Water-Borne & High-Solids coatings	70-95
Sheet Coating	Carbon Adsorption	90
	Catalytic and non-catalytic incineration	90
	Water-Borne & High-Solids coatings	60-90

*Any sheet, can or end coating line consists of the coater(s) and ovens(s).

2.2 General Discussion

Cans are made in one of two different ways. A "three-piece" can is made from a rectangular sheet (body blank) and two circular ends. The metal sheet is rolled into a cylinder and soldered, welded or cemented at the seam. One end is attached during manufacturing, the other during packaging of the product. The "two-piece" can is drawn and wall-ironed from a shallow cup and requires only one end which is attached after the can is filled with a product.

Cans are used as containers for over 2500 different products ranging from beer and other beverages, meats, fruit, vegetables and other edible products to tennis balls, motor oil and paints. Cans are fabricated in over 600 different shapes, styles and sizes. There are, therefore, major differences in coating practices depending on the can and type of product packaged in the can.

Independent and captive can manufacturers make up the industry. The independents are a service industry that coat and fabricate cans for a variety of customer's needs and specifications. A few plants are owned by independent companies but manufacture cans for a single customer. Captive can manufacturers coat and fabricate containers only for products of that corporation.

Can manufacturing plants are typically located either near steel or aluminum mills or in the vicinity of their customers. In the independent can industry, the metal sheets for three-piece cans are usually coated near steel mills, and the cans are usually fabricated near the customers. The captive can industry typically coats and fabricates cans in the vicinity of the plant that uses the cans. About 50 percent of the U.S. can coating industry is located in California, Illinois, Ohio, Texas, Pennsylvania and New Jersey. On a regional basis, EPA Region V has about 27 percent of the U.S. can industry, Region IX about 16 percent and Region III about 12 percent.

Sizes of can manufacturing plants vary. Some plants coat only the metal sheets, some fabricate only the three-piece cans from the coated sheets, some fabricate and coat only two-piece cans, and some coat and fabricate only can ends. Other plants perform combinations of these processes.

2.2.1 Materials Used - The metal sheets typically coated in the three-piece can manufacturing industry are tinplate, tin-free steel, black plate and aluminum in gauges ranging from 0.006 to 0.015 inch and sheet sizes ranging from 30 inches x 32 inches to 37 inches x 42 inches. Aluminum is widely used in two-piece can manufacturing but some steel is also used.

The interior base coat is roll coated on the sheets for three-piece cans to provide a protective lining between the can metal and product. It is important that the interior base coat does not react with the product to alter the product's taste, odor, or appearance. All interior coatings for cans that will contain edible products must meet Food and Drug Administration regulations.[1,2]

Some common resins used in the interior base coat are butadienes, rosin esters, phenolics, epoxies, and vinyls. The coatings in which these resins are used range from 20 to 60 percent solids by weight, and organosols that range from 30 to 66 percent solids by weight.[1,2]

The exterior base coat, usually white, is used frequently both on two and three piece cans to provide exterior protection to the metal and background for the lithograph or printing operations. Some of the coating resins used are polyesters, alkyds and acrylics. These coatings are approximately 55 to 72 percent solids by weight.

Conventional inks used for printing or lithography contain approximately 90 to 99 percent solids by weight.[1] These inks may be used for both two and three-piece cans, with or without exterior base coat as specified by the customer.

An over-varnish is usually applied directly over the inks to reduce the coefficient of friction (to allow for proper mobility of the can on conveyor tracks), to provide gloss, and to protect the finish against abrasion and corrosion. Some common solvent-thinned coating resins are acrylics, epoxies, alkyds, and polyesters at solids contents of 30 to 45 percent by weight.[1,3]

The primer or size coat is roll coated before the application of the exterior base coat or ink to provide better adhesion of the coating, especially if a coating has to withstand severe deformation during stamping or tooling operations or withstand high temperature processing operations. The sizing is usually an epoxy, epoxy ester, acrylic, vinyl or polyester resin.

Over 30 different solvents are used in interior and exterior base coats, overvarnish and size coat. These include mineral spirits, xylene, toluene, diacetone alcohol, methyl iso-butyl ketone, methyl ethyl ketone, isophorone, Solvesso 100 and 150 (TM), ethylene glycol monoethyl ether (TM under Cellosolve), ethanol, cyclohexanone, ethylene glycol monobutyl ether (TM under Butyl Cellosolve), ethylene glycol monoethyl ether acetate (TM under Cellosolve acetate), n-butanol, isopropanol, butyl carbinol, paraffins, propylene oxide, mesityl oxide, aliphatic petroleum hydrocarbons, di-isobutyl ketone, di-methyl formamide, and nitropropane.

The coating used for the sideseam on the interior and sometimes on the exterior of three-piece cans usually contains vinyl and epoxy-phenolic resins at 10 to 40 percent solids by weight. Solvents used in side-seam coatings are xylene, butyl acetate, paraffins, nitropropane, Cellosolve acetate (TM), methyl iso-butyl ketone, mineral spirits, propylene oxides and toluene.[1,4]

The end sealing compound is usually a dispersion of a synthetic rubber in heptane or hexane, and lines the edges of can ends to form a gasket. It contains 30-45 percent solids by weight.[1]

2.2.2 Processes and Affected Facilities

Two-Piece Cans - The two-piece can manufacturing operation is a continuous, high speed process and includes both fabricating and coating operations. These cans are typically used by the beer and other beverage industries. Figure 2-1 shows one method of fabricating and coating two-piece aluminum cans.

Metal for two-piece cans is received in coil form and is continuously fed into a press (cupper) that stamps and forms a shallow cup. The cups go through an extrusion process that draws and wall-irons the cups into cans in a lubricating solution and trims the uneven edge of the cans. The cans are then cleansed to remove the lubricating solution, rinsed with hot water, and dried. Some manufacturers have been required to provide water treatment facilities to treat the cleansing process water prior to disposal.

The exterior bodies of these cans are sometimes reverse-roller coated with a white base coat. The base coat is transferred from a feed tray, through a series of rollers, and onto the can, which rotates on a mandrel. The coating is cured or baked at 350 to 400°F in single or multi-pass continuous, high production ovens at a rate of 500 to 2000 cans per minute.

Several colors of ink are applied to printing blankets on a rotary printer that transfers the designs and lettering to the can as it rotates on a mandrel. A protective varnish is sometimes roll coated directly over the inks. The decorative coating is cured or baked in single or multi-pass, continuous, high production ovens at 325 to 400°F.

After printing, the cans are necked, flanged, and tested. Flanging facilitates proper end assembly once the can is filled. Necking allows use of a smaller end. Each can is tested for leakage by applying approximately 12 psig of air pressure and monitoring the can for air leakage.

The cans are spray-coated on the interior of the can body and spray and/or roll coated on the exterior of the bottom end. The viscosity, spray time, atomization pressure, and temperature during application of the coating require precise control to provide a continuous protective film between the product and the can.[2]

The coating is usually cured or baked in a continuous, single pass oven at temperatures of 225 to 400°F. Coated cans are stacked on pallets for shipment to users.

Some two-piece steel cans are sprayed with an additional interior coating and baked prior to the application of the interior body spray. Also the cans are necked in and flanged after the final step.

Three-Piece Cans - The three-piece can manufacturing process can be divided into two operations: sheet coating and can fabricating. The sheet coating operation may be subdivided further into base coating of one or both sides and the printing or lithographing. The base coating operation consists of applying an interior coating for three-piece cans and can ends, an exterior background coating, or a size coat if the customer so chooses.

The sheets are roll coated on one side only by transfer of the coating from the coating tray, through a series of rollers, and onto the sheet as shown in Figure 2.2. Sheets are then picked up by the preheated wickets and transported through a continuous, multi-zone, oven. The coating is cured at temperatures of up to 425°F. Speeds are 70 to 150 sheets per minute, depending on the age of equipment and the type of coating. The sheets are air cooled in the last zone of the oven. Oven exhaust rates usually vary between 2,000 and 14,000 scfm.

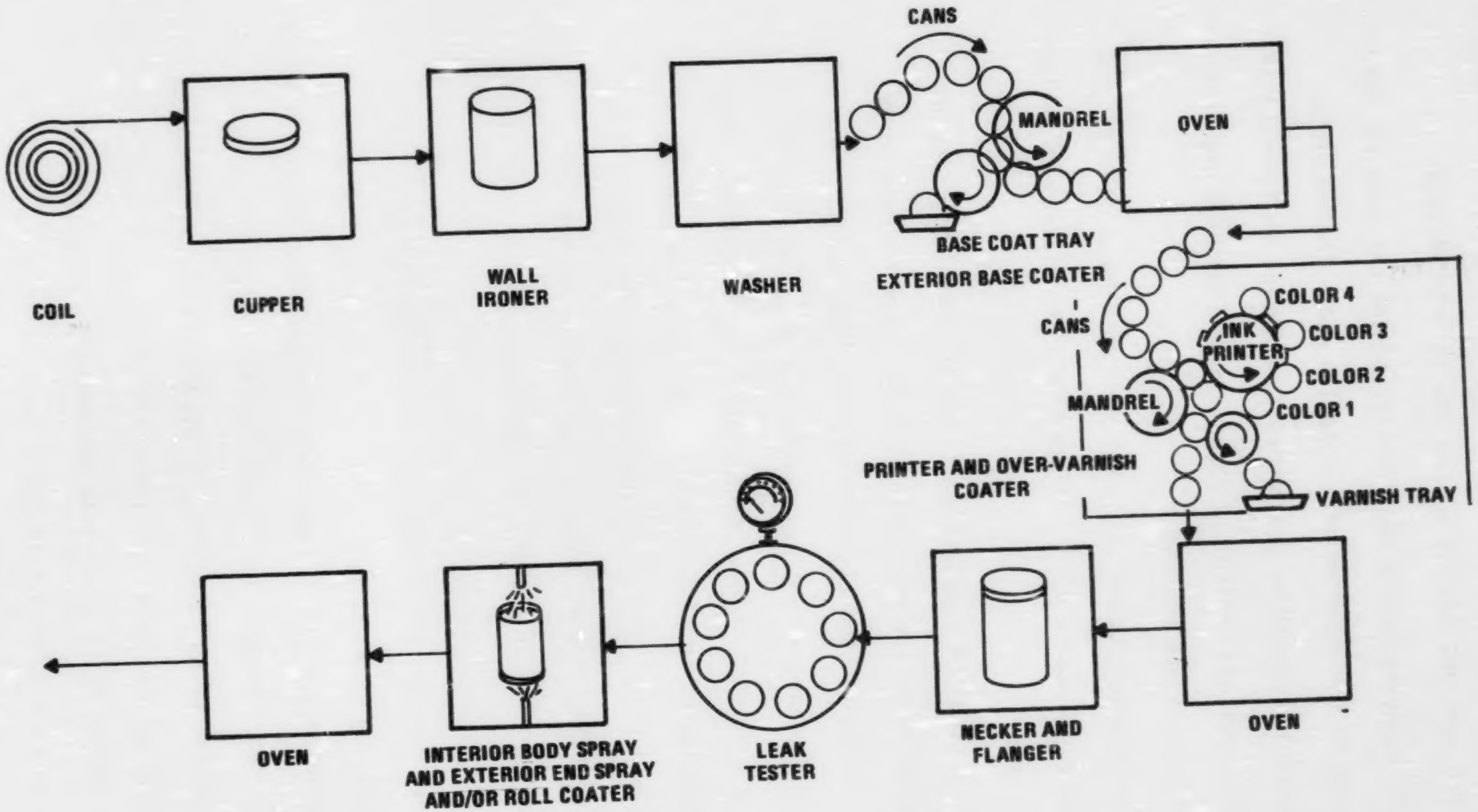
CANS
MANDREL
OVEN
COIL
CUPPER
WALL IRONER
WASHER
BASE COAT TRAY
EXTERIOR BASE COATER
CANS
COLOR 4
INK
PRINTER
COLOR 3
COLOR 2
COLOR 1
MANDREL
PRINTER AND OVER-VARNISH COATER
VARNISH TRAY
OVEN
INTERIOR BODY SPRAY AND EXTERIOR END SPRAY AND/OR ROLL COATER
LEAK TESTER
NECKER AND FLANGER
OVEN

Figure 2-1. Diagram of two-piece aluminum can fabricating and coating operation.

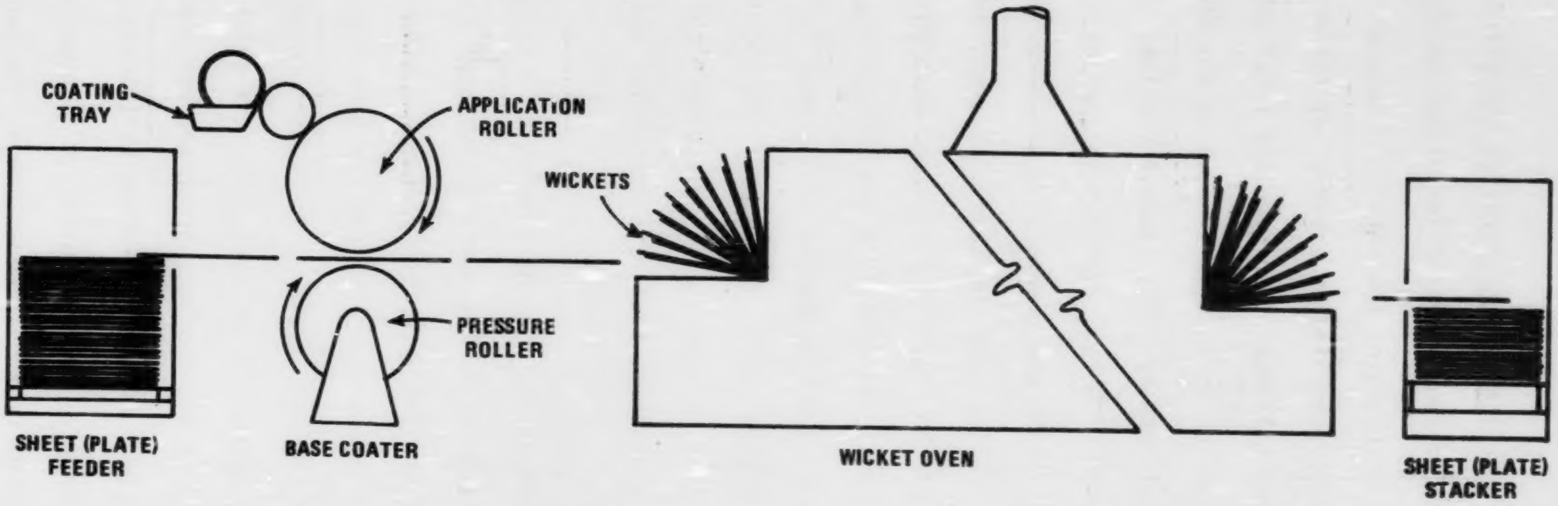
COATING TRAY
APPLICATION ROLLER
WICKETS
SHEET (PLATE) FEEDER
PRESSURE ROLLER
BASE COATER
WICKET OVEN
SHEET (PLATE) STACKER

Figure 2-2. Sheet base coating operation.

The sheet printing or lithograph operation (graphic arts) usually consists of applying one or two colors of ink either on the exterior base coat, the size coat, or directly on the metal. A varnish is applied directly over the wet inks. Inks are applied by a series of rollers transferring the design first to a blanket cylinder, then onto the metal sheet as shown in Figure 2-3. The transfer of inks is influenced by environmental factors such as temperature, draft and humidity because the inks can become emulsified in the presence of water. Varnish is applied to the metal sheets by a direct roll coater. Inks and overvarnish are cured in a wicket oven similar to but usually smaller than the base coat oven; exhaust rates are 1,500 to 8,000 scfm.[3] If the required design has more than two colors, the first set of inks is dried in an oven. Another set of inks is then applied followed by an overvarnish and then baking in an oven.

During the past several years, ultraviolet light curable inks have been developed which permit the application of up to 4 colors in a single pass. In addition, some printing inks have been developed that do not require an overvarnish.

The can fabricating process is the forming of cans from the coated sheets. Some of these cans have flat surfaces and some are beaded for extra strength. Figure 2-4 describes a beer and other beverage three-piece can fabricating line. Sheets are slit into can body size blanks and fed into a "body maker" in which the body blank is formed into a cylinder. The seam is welded, cemented, or soldered, and sprayed on the exterior and interior of the seam with usually an air-dry lacquer to protect the exposed metal. On some cans other than beer or other beverage containers, the coating is usually sprayed only on the interior. The cylinders are flanged to provide proper can end assembly and may be necked-in depending on the customer's specifications.

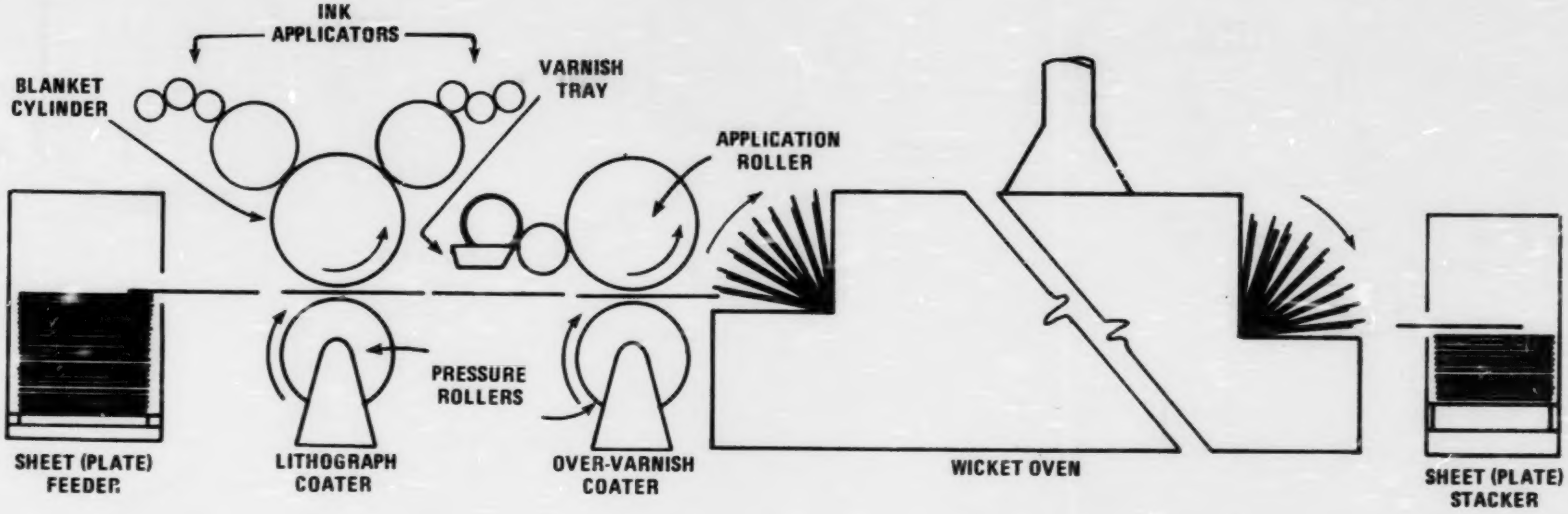
INK APPLICATORS
BLANKET CYLINDER
VARNISH TRAY
APPLICATION ROLLER
PRESSURE ROLLERS
SHEET (PLATE) FEEDER
LITHOGRAPH COATER
OVER-VARNISH COATER
WICKET OVEN
SHEET (PLATE) STACKER

Figure 2-3. Sheet printing operation.

CAN END, AND THREE-PIECE BEER AND BEVERAGE CAN FABRICATING OPERATION

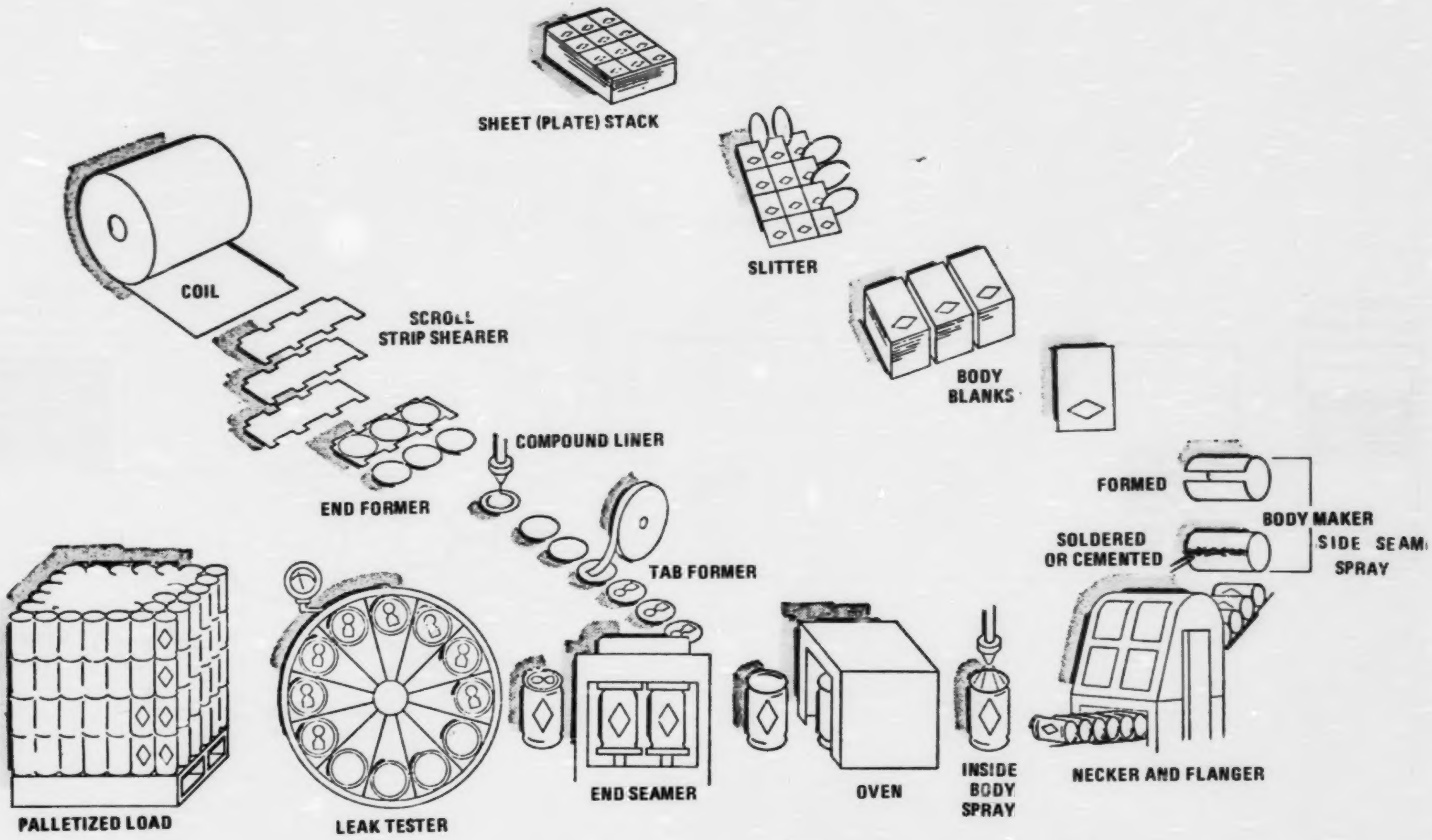
SHEET (PLATE) STACK
COIL
SLITTER
SCROLL
STRIP SHEARER
BODY
BLANKS
COMPOUND LINER
END FORMER
FORMED
BODY MAKER
SOLDERED
OR CEMENTED
SIDE SEAM
SPRAY
TAB FORMER
PALLETIZED LOAD
LEAK TESTER
END SEAMER
OVEN
INSIDE
BODY
SPRAY
NECKER AND FLANGER

Figure 2-4. Can end, and three-piece beer and beverage can fabricating operation.

The interior of the cylinder is sprayed with a coating to ensure a protective lining between the beer or other beverage and the can. Cans used for other products are typically not spray coated.

The spray coating is usually cured or baked in single pass vertical or horizontal ovens at temperatures of up to 425°F. The oven exhaust rate is approximately 2,000 scfm.

Open cylinders pass through an "end double seamer" that attaches one end onto the cylinder. The cans are tested for leakage, then stacked and palletized for shipment.

Can ends are stamped from coated sheets of metal in a reciprocating press and the perimeter coated with a synthetic rubber compound that functions as a gasket when the end is assembled on the can. Solvent-based compounds are usually air dried and water-based compounds oven dried at approximately 110°F. The oven exhaust rate is about 300 scfm.

Table 2-1 summarizes some typical oven exhaust rates, organic solvent concentrations, type of fuel used for the curing or baking operations, and control methods used in the can industry.

Typical organic emission rates for can coating lines are listed in Table 2-2. For sheet coating lines, 88 to 92 percent of the solvent is estimated to be evaporated in the oven. For interior coating, side seam and coating and end sealing compound lines, most of the solvent evaporates in the coating operation.[1,4]

2.3 Special Considerations

Independent manufacturers have less control over the coatings used than captive manufacturers because the independents must satisfy a broad range of customers' product needs and specifications. An independent may use as many as 300 different coating formulations.

TABLE 2-1 OPERATION OF TYPICAL CAN COATING FACILITIES

PLANT	PROCESS	OVEN TEMPERATURE (°F)	OVEN EXHAUST RATE IN SCFM	EXHAUST GAS SOLVENT CONCENTRATION % LEL	FUEL	CONTROL METHOD(S)
Sheet Coating	Sheet Base Coating (exterior & interior)	400	8,000-10,000	12	Natural Gas	Each oven has a thermal incinerator
	Sheet Printing	380	4,000-5,000	10-12	Natural Gas	All ovens ducted into one incinerator.
	Side Seam	Air-dried	-	-		None.
	Interior Body Spray	300-350	2,000-3,000	10-12	Natural Gas	Some water-borne.
Two-Piece Cans	Exterior Base Coat	385	6,000	8-15	Natural Gas And Propane Backup	Single 20,000 scfm thermal incinerator, primary and secondary heat recovery.
	Lithograph and Overvarnish	385	4,000	8-15		
	Interior Body and Exterior End Spray	365	2,000	8-15		
Sheet Coating	Exterior and Interior Base Coat	400	5,000-6,000	5-10	Natural Gas And Propane Backup	Use some water-borne; plan on going to water-borne, high-solids and UV coatings. Use UV for some inks.
	Sheet Lithograph	380	3,500-4,000	5-10		
Sheet Coating, Three-Piece Cans, Two-Piece Cans	Sheet Exterior and Interior Base Coat	350-400	4,900	5-15		Catalytic incineration, plan on going to water-borne and high-solids.
	Sheet Printing	315	3,500	3-12	Natural Gas And Propane Backup	Plan on going to water-borne, high-solids, and no-var inks.
	Side Seam	Air-dried	-	-		None.
	Interior Body Spray	300	2,200	10-15		Water-borne on some lines.
	Two-Piece: Exterior Base Coat	400	2,200	5-15		Plan on going to water-borne and high-solids.
	Lithograph	325	2,000	5-15		Plan on going to water-borne varnish or no-var inks.
	Interior Body Spray and End Spray/Rollcoat	225	2,200	10-15		Use water-borne on some lines.
Sheet Coating, Three-Piece Cans and Ends	Sheet Coating	350-425	8,000-9,000	10-15	Natural Gas And Propane Backup	Carbon adsorber (being replaced by a catalytic incinerator).
	Side Seam	Air-dried	-	-		None.
	Ends	Air-dried	-	-		Use some water-borne coatings.
Three-Piece Can Fabrication (only beer and beverage cans)	Side Seam	Air-dried	-	-	Natural Gas	None.
	Interior Body Spray	300-350	2,000	10-15		None.

Table 2-2 ORGANIC SOLVENT EMISSIONS FROM CAN COATING PROCESSES

Process	Typical volatile organic emissions from coating line, lb/hr	Estimated fraction of emissions from coater area	Estimated fraction of emissions from oven	Typical organic emissions, tons/yr[b]
Sheet base coating line	112	9-12	88-91	160
Sheet lithographic coating line	65	8-11	89-92	50
Beer and beverage can-side seam spray coating process	12	100	air-dried	18
Beer and beverage can-interior body spray coating process	54	75-85	15-25	80
Two-piece can coating line	86	uncertain	uncertain	260
End sealing compound line	8	100	air-dried	14

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[a] Organic solvent emissions will vary from line to line as a result of line speed, size of can or sheet being coated, and type of coating used.

[b] Based upon normal operating conditions.

Interior coatings must comply with U. S. Food and Drug Administration (FDA) Regulation No. 121.2514 if the cans are to contain edible products. The FDA determines compliance with the regulation through a lengthy test program. First, the coating must be tested to verify that all of the components in that coating are specified in the FDA list of approved components. Other tests must be performed to verify that extractables from that coating are less than 50 ppm. If a coating contains new components not previously tested by the FDA, an extended period may be required for suitable testing.

Frequently, the customer also performs long-range storage tests (as long as 18 months) with the interior coating in contact with the product to determine if there is any change in the product. Interior coatings must prevent the product from reacting with the can, and the coatings must not react with the product to alter its taste, odor, or color. Exterior coatings must meet requirements for flow, gloss, color, hiding, adhesion, fabrication, blocking, pasteurization, and retorting temperature resistance. Both exterior and interior coatings are applied in very thin films, usually round 0.0003 inches. In the can industry, film thickness is expressed in mg/sq. inch; most range from 1 to 15.

Plants subject to interruptions in natural gas supply typically use liquefied petroleum gas (LPG) as backup fuel for can ovens. Sulfur dioxide and other products of combustion of fuel oil may contaminate the coating and affect product taste. However, if less efficient indirect fired ovens are employed, fuel oil is acceptable.

Most can coating ovens are designed to operate at 25 percent of the lower explosive limit (LEL). Some can manufacturers, especially independents, operate their ovens at only 5 to 15 percent of the LEL. This is less efficient from both an energy and air pollution control standpoint because larger volumes of air must be handled and processed. Some of the reasons cited for operating at lower LEL levels are: the variety of temperatures and speeds required for different coatings, diverse sheet sizes, air volume distribution requirements, uneven evaporation rates, and the tendency of LEL sensing devices to foul. Coaters that use uniform coatings and coat uniform sizes of cans or sheets are more likely to operate their ovens closer to 25 percent of the LEL than coaters which use a large variety of coatings.

Equipment used for can coating and fabricating varies with age and type of cans coated and manufactured, therefore, the ease of application of pollution control technology will vary. Some existing equipment can apply low solvent coatings without major costs and alterations; other equipment must be replaced or extensively modified. Also, add-on control equipment is more costly to retrofit to some lines than others depending on the extent of line equipment alterations and structural changes.

The following sections discuss the use of incineration and carbon adsorption, and conversion to water-borne, high-solids, powder, and ultraviolet curable coatings to reduce organic emissions.

2.4 Available Control Technology

2.4.1 Option 1 - Incineration

Achievable Reductions - Reductions of organic emissions of 90 to 98 percent from can coating ovens are achievable using non-catalytic incinerators. At least 90 percent control is attainable by catalytic incineration systems.

Technical Analysis: Catalytic Incineration - Catalytic incineration frequently can oxidize organic emissions efficiently at catalyst inlet gas stream temperatures of 500 to 600°F and outlet gas temperatures of 750 to 1,000°F.

Catalysts used in catalytic incineration are usually made of platinum and therefore, are relatively expensive and may be poisoned. Its activity or effectiveness is adversely affected by normal aging, high temperature, and particulate matter, sulfur oxides, and other contaminants. Natural gas or propane are the preferred fuels for catalytic incineration because their combustion products will not adversely affect the catalysts. Normal catalyst life on a can coating line can be 2 to 4 years if the catalyst is not subjected to overheating, due to higher inlet temperatures and/or higher concentrations, and is not poisoned.

Catalyst efficiency may be monitored by a hydrocarbon analyzer or in terms of temperature rise and/or pressure drop across the bed. Routine inspection and periodic cleaning are needed to insure optimum oxidation of volatile organics.

For details on catalytic incineration, refer to Volume I, Section 3.2.2 of this series.

Table 2-3 presents a comparison of burner fuel requirements for catalytic incineration with and without heat recovery for two flow rates: 5,000 and 15,000 scfm. As shown in Table 2-3, fuel requirements decrease with the use of heat recovery. When using both primary and secondary heat recovery, a net line fuel savings is possible with use of incineration if all the energy available for recovery can be utilized. As the temperature of the inlet process gas stream increases and/or the concentration of organics in the gas stream increases above 15 percent LEL, the potential net fuel savings using both primary and secondary heat recovery would even be greater. As the gas stream concentration approaches 25 percent LEL, the fuel value of the oven exhaust stream increases. If all other factors remain constant,

TABLE 2-3 BURNER REQUIREMENTS FOR CATALYTIC INCINERATION WITH VARYING DEGREES OF HEAT RECOVERY[a,5]

Method	Process gas flow rate into incinerator, scfm	
	5,000	15,000
Catalytic incineration, no heat recovery		
Burner requirements, 10^6 Btu/hr		
Net	1.69	5.07
Gross	1.80	5.39
Catalytic incineration with primary heat recovery		
Primary heat exchanger efficiency, percent	36.8	36.8
Burner requirements, 10^6 Btu/hr		
Net	0.26	0.77
Gross	0.27	0.82
Catalytic incineration with primary and secondary heat recovery		
Secondary air flow, scfm	15,000	45,000
Secondary heat exchanger efficiency, percent	53.8	53.8
Heat recovered, 10^6 Btu/hr	1.33	3.99
Net fuel savings, 10^6 Btu/hr[b]	1.07	3.22

[a] 300°F process inlet gas stream, 15 percent LEL concentration.

[b] Energy that may be used for energy using facilities other than an incinerator.

the temperature of the catalyst bed will increase and its design temperature may be exceeded. Therefore, the operator may not always be able to utilize all of the energy potentially recoverable with a primary system.

Technical Analysis: Non-Catalytic Incineration - Many organic emissions will oxidize at temperatures of 1,100°F to 1,250°F. Cellosolves (TM), toluene, xylene, and some other organics, however, require 1,400°F to 1,500°F. Effective oxidation is also dependent on residence time and mixing in the incinerator. Partially oxidized compounds can be formed if non-catalytic incinerators are not maintained at proper oxidation temperatures and residence times. Non-catalytic incineration will also increase NO_x levels somewhat over those experienced with catalytic units.

For details on non-catalytic incinerators, refer to Volume I, Section 3.2.2.

Table 2-4 presents a comparison of incinerator fuel requirements for two flow rates (5,000 and 15,000 scfm) and two cases: with and without heat recovery. Fuel requirements decrease with primary heat recovery, more so with both primary and secondary heat recovery. A net fuel savings may accrue by using both primary and secondary heat recovery if all of the recovered energy can be utilized. Moreover, as the temperature or organic concentration of the inlet process gas stream increases, there will be an even greater net fuel savings if the available heat can be utilized. However, the can coaters may often apply a variety of coatings on a line at various organic solvent contents resulting in varied emission concentrations and variable fuel requirements.

As shown in Table 2-1, some can coaters are presently using incineration, typically with 45 percent efficient primary heat recovery, to control emissions from sheet coating facilities and two-piece can coating facilities. Some

TABLE 2-4 BURNER REQUIREMENTS FOR NON-CATALYTIC INCINERATORS WITH VARYING DEGREES OF HEAT RECOVERY[a,5]

Method	Process gas flow rate into incinerator, scfm	
	5,000	15,000
Thermal incineration, no heat recovery		
Burner requirements, 10^6 Btu/hr		
Net	4.05	12.16
Gross	4.30	12.93
Thermal incineration with primary heat recovery		
Primary heat exchanger efficiency, percent	38.5	38.5
Burner requirements, 10^6 Btu/hr		
Net	1.56	1.66
Gross	4.73	5.03
Thermal incineration with primary and secondary heat recovery		
Secondary air flow, scfm	15,000	45,000
Secondary heat exchanger efficiency, percent	55.2	55.2
Btu recovered, 10^6 Btu/hr	1.90	5.69
Net fuel savings, 10^6 Btu/hr[b]	0.34	0.66

[a] 300°F process inlet gas stream; 15 percent LEL concentration.

[b] Energy that may be used for energy using facilities other than an incinerator.

secondary heat recovery is used for preheating the wickets on sheet coating lines, and for the washers and dryers on two-piece can coating lines.

Costs of Control Option - The value of recovered energy does not completely compensate for added operating costs. Table 2-5 provides a comparison of estimated annual operating costs for various degrees of heat recovery. These costs were derived for "ideal" facilities using 5,000 and 15,000 scfm flow rates at 15 percent of the LEL concentration. It was assumed that the cost of installation is about 40 percent of the equipment costs. However, the varying degrees of difficulty of retrofitting an incinerator to an existing facility could increase installation costs by a factor of 2 to 4. The age and type of can coating equipment, the price of fuel and electricity, labor, water, engineering costs and the percent operating time where there is solvent input will cause operating costs to vary for each facility.

Catalytic incineration, as shown in Table 2-5, is less costly than thermal incineration in all cases for 5,000 scfm flow rates and for two cases with 15,000 scfm flow rates. However, catalytic incineration is almost equal in cost to thermal incineration for the 15,000 scfm primary and secondary heat recovery cases. As more energy is recovered, operating costs of either type incinerator decrease.

For detailed costs of thermal and catalytic incineration, see Volume I, section 4 of this series.

Effects and Limitations - Adverse environmental effects from incinerators are mostly dependent on fuels and compounds present in the gas stream. If sulfur or nitrogen compounds are present, their oxides can be generated. If halogens are present, their acids will be formed. Sulfur oxides will be generated by sulfur in the fuel oil or in the oven gases. Some nitrogen oxides are always generated by air fixation.

TABLE 2-5 ESTIMATED ANNUAL OPERATING COSTS FOR THERMAL AND CATALYTIC INCINERATION[a,b,5]

FLOW RATE INTO INCINERATOR:	5,000 SCFM		15,000 SCFM	
Type of Incineration	Annual operating cost range, dollars	Cost per ton of organics removed range, dollars	Annual operating cost range, dollars	Cost per ton of organics removed range, dollars
Thermal, no heat recovery	72,810-91,800	218-918	168,560-225,560	169-752
Thermal, primary heat recovery only	52,550-70,550	158-706	99,560-156,560	100-522
Thermal, primary and secondary heat recovery	39,870-57,850	120-579	52,680-109,680	53-366
Catalytic, no heat recovery	55,040	165-550	120,390	121-401
Catalytic, primary heat recovery only	45,000-49,950	135-500	85,450-102,450	86-342
Catalytic, primary and secondary heat recovery	37,310-45,310	112-453	55,060-82,090	55-274

[a] 300°F process inlet gas temperature; 5-15 percent LEL concentration range; $\$2.00/10^6$ Btu fuel cost; tube and shell heat exchangers.

[b] These calculations are based on continuous 5000 hours per year operating time. However, due to the variety of coatings applied, and often frequent coating changes in non-captive facilities, the actual operating time when organic solvents are being emitted may not be 5000 hours per year.

The can industry has generally avoided using fuel-oil-fired ovens because of potential sulfur contamination that may affect the product taste. Using fuel oil in the incinerator would necessitate indirect heat-exchangers to ensure that sulfur compounds do not reach the ovens.

It is important to note that the energy contribution of the oven exhaust will vary considerably. Solvent will actually enter an incinerator from many sheet and can coating facilities rarely more than 75 percent of the operating time of that facility due to coating changes, preparation period, etc. During this time, the oven and incinerators must be maintained at operating temperatures, thus using additional fuel. In addition, the solvent concentration will vary due to coating composition, film thickness, line speed, sheet size, etc. To compensate for these variations, it is common to install a bypass around the primary heat exchanger. Then during periods when the exhaust gas contains less organics, the bypass can be throttled to maximize the inlet temperature to the incinerator.

Incineration is applicable for sheet coating facilities, two-piece can facilities and three-piece interior body spray coating facilities, because of their relatively high oven temperature and organic concentration (around 10 percent of the LEL). Capturing and incinerating the volatile organics from side seam spray coaters and end sealing compound applicators is more costly and energy intensive because: the exhaust is usually at ambient temperatures, gas volumes would be large and would contain relatively low concentrations of organics, and since these coatings are air-dried, there may be no nearby energy using facilities that can benefit from the recovered energy.

2.4.2 Option 2 - Water-Borne/High-Solids/Powder Coatings

Achievable Reduction - The potential reduction of organic emissions from converting to water-borne coatings and high-solids coatings is 60 to 90 percent. This depends on the solvent content of the original coating. The reduction from conversion to powder coating approaches 100 percent.

Technical Analysis: Water-Borne Coatings - Water-borne coatings contain a polymer or resin base, water, some organic "cosolvent" and solubilizing agent. The presence of some organic solvent in water-borne coatings is necessary to improve stability, flow-out, appearance, as well as to depress foaming, and control the evaporation rate.[6]

Problems associated with conversion to water-borne coatings often vary due to application characteristics and the type of equipment available. The replacement of certain existing equipment is usually necessary to protect against corrosion.

Water-borne coatings may be applied by conventional techniques and other newer methods. One newer method, currently used for some two-piece beer cans is to apply a water-borne base coat on the entire can during the final stages of the cleansing section, then bake the coating in an oven. Another method, in the experimental stages, is to coat the interior of two-piece cans by filling them with a water-borne coating, applying a charge and electrodepositing the coating particles onto the can. This method of application, however, is relatively slow and might require several such units on each line. This could be a disadvantage to an older plant which does not have enough room to install these applications.

The temperatures of the oven zones have to be adjusted to avoid "pitting" the water-borne coating film. Although some water-borne coatings may require higher curing temperatures, this increase in energy consumption may be balanced by a significant reduction in oven exhaust flow because of the reduced input of volatile organics.

Water-borne coatings are often difficult to clean up after they have dried because they do not remain soluble in their carrier. Also, water-borne coatings should be protected in transport and storage during winter and summer months. For details on water-borne coatings, see Volume I, section 3.3.1 of this series.

Technical Analysis: High-Solids Coatings - "High-solids" coatings have been defined by various agencies as those with volatile solvent contents of only 20 or 30 percent by volume. To convert a process to a high-solids coating may present application difficulties because of the high viscosity of the material. To lower viscosity, it may be necessary to raise the application temperature by installing a heating unit as well as changing the application equipment. For details on high-solids coatings, see Volume I, Section 3.3.2 of this series.

Technical Analysis: Powder Coatings - Powder coatings approach 100 percent solids. Converting to powder coatings necessitates a major change of application equipment. Powder coating application technology is being pursued in the can industry for two-piece can interiors, and has been used for the side seam coating of non-cemented three-piece cans. Powder coatings may also be applicable as an overvarnish on two-piece cans. However, present powder coating application technology has not been perfected to produce the thin continuous film on the can at high speeds, as with solvent or water-borne. For details on powder coatings, see Section 3.3.3 of Volume I of this series.

Cost of Control Options - The cost of converting to water-borne, high-solids, or powder coatings will vary from plant to plant depending on the type of cans, and the age and design of application equipment. Some application equipment may require only small adjustments or the replacement of a spray nozzle; others will require much more extensive modification.

Water-borne, high-solids and powder coatings are often more expensive than the pure organic solvent-borne coatings.[7] With increased consumption, further development and the increasing costs of organic solvents, the overall cost of low solvent coatings may become less than conventional organic solvent-borne coatings.

Secondary costs for conversion to low solvent coatings include: refinements needed to meet customer's specifications and Federal Food and Drug Administration standards. One independent can company reportedly has spent more than $4,000,000 in the last 3 years in the development and testing of water-borne, high-solids, powder and "exempt" solvent coatings.[4,8,9]

Effects and Limitations - Some water-borne, high-solids and powder coatings have been developed for the can industry that are comparable in performance to solvent-borne coatings; they also comply with FDA standards. Since these coatings are new to the industry, many customers require extensive testing because their different friction characteristics may affect the mobility of the cans during packaging or they may change the taste of the product. Many customers conduct independent tests to determine effects of a coating on their product.

The can industry applies very thin films of coating. Many of these coatings, such as the side seam spray and interior body spray coatings, are low solids (10-18 volume percent) coatings at 6.0 to 6.6 pounds of organic solvent for each gallon of coating (minus water). Water-borne coatings available for some of those applications contain 3.5 to 4.0 pounds per gallon (minus water).[10,11] This represents about an 80 percent reduction in organic emissions over conventional organic coatings. Available water-borne and high-solids sheet and can exterior base coats and overvarnishes can contain about 2.2 pounds per gallon (minus water). The sheet interior water-borne or high-solids base coats may contain 2.2 to 2.8 pounds per gallon (minus water).[10]

Water-borne, high-solids or powder coatings are not available to replace all the present organic solvent-borne formulations used in the can industry. Therefore, this option is not universal. However, availability of these systems is predicted to increase substantially over the next several years.

2.4.3 Control Option 3 - Carbon Adsorption

Achievable Reductions - Carbon adsorption units can be used to control organic emissions with an efficiency of 85 to 90 percent.[1]

Technical Analysis - A single carbon adsorption unit may be installed on one can coating facility or on several coating lines together depending on the location of the coating lines and the type of coating being performed.

Carbon adsorption is most adaptable to "low temperature" processes using a limited number of solvents such as the can end sealing compound or the interior body spray coater for beer and beverage cans, because collecting mixtures of solvents can be difficult.

Coatings in the can industry may contain as many as ten solvents. Because of the difficulty in separating them, the recovered solvent is probably best used as boiler fuel for generating steam for the regeneration of the carbon bed. If the solvent is recovered for reuse, additional distillation would probably be necessary to render it acceptable for reuse in can coating.

Process gas streams must be cooled below 100°F for carbon adsorption to be effective. Also particulate collection may be required since particulate matter will coat the carbon bed and reduce its adsorption efficiency. Carbon adsorption systems are not practical if non-filterable matter is present in the gas stream. For example, silicone coatings will coat the carbon bed and prevent adsorption. Corrosion of equipment can occur if the solvents contain acid-forming compounds. If the carbon adsorption units are located out of doors, improper operation may be encountered on cold winter days unless care is taken in the design.

An experimental carbon adsorption system that uses the recoverd solvent as fuel to produce steam for the regeneration of the carbon bed is known to have been retrofitted to one can coating facility, a sheet coating line. This unit has not been successful due to plugging of the carbon bed by condensables and polymerization of some solvents.

Other cited problems are: high operating costs, water-soluble solvents causing water pollution, corroding of the carbon support screen, short useful life of the carbon, and large fuel and water usage for steam regeneration. This system is reportedly being replaced with a catalytic incinerator. Many of these problems causing the carbon adsorber to function improperly were related to the relatively higher operating temperatures of the oven and the mixtures of solvents used. Carbon adsorption is technically feasible for "lower" temperature operations such as the end sealing compound, side seam spray or the interior body spray of both two and three-piece cans. However, capture of the volatile emissions from the sealing compound and the side seam application areas may be difficult and costly. This technique, although technically feasible, has not been commercially demonstrated. For details on carbon adsorption, see Volume I, Section 3.2.1 of this series.

Cost of Control Option - The costs of carbon adsorption systems to control organic emissions are summarized in Table 2-6. These costs were derived for an "ideal" facility, where the installation cost is about 40 percent of the cost of equipment. Installation costs will vary depending on the plant involved and will be higher when retrofitting a carbon adsorber on an existing facility.

The cost figures are for carbon steel equipment, although some solvents such as ketones will require more costly alloys to avoid corrosion. Costs will increase also if distillation equipment or filtration of the process gas stream is necessary. For additional cost data, see Volume I, section 4 of this series.

TABLE 2-6. COST OF CARBON ADSORPTION IN CAN COATING INDUSTRY[a,b]

Costs	No credit for recovered solvent	Recovered solvent credited at fuel value	Recovered solvent at market chemical value
Installed cost, $			
5,000 scfm	162,000	162,000	162,000
15,000 scfm	302,000	302,000	302,000
Annual operating cost, $			
5,000 scfm	60,000	42,000	15,000
15,000 scfm	142,000	90,000	1,000
Cost of collected solvents, $/ton			
5,000 scfm	255	215	100
15,000 scfm	145	105	-5[c]

[a] 300°F inlet process gas temperature; 15 percent of LEL concentration.

[b] Installation cost assumed to be 40 percent of equipment cost.

[c] Cost indicates a net gain.

Effects and Limitations - The oven gas stream may contain not only the organic vapors from the coating but also other products such as from thermal degradation and volatilization of resin. Some of these may condense to sticky tar-like particulates. In such a case, the gas stream must be filtered or scrubbed upstream of the adsorber and the solid waste must be disposed in an environmentally acceptable manner. If the filter does not remove these particulates, the carbon bed will foul. When solvents that are miscible in water are used, the condensate from the steam used to regenerate the carbon bed may have to be heated to remove the solvents to avoid a water pollution problem. Any boiler operating on recovered solvent must be supplementally fired because of the typically low organic concentrations of the process gas and the potential water loss of any miscible organics during steam regeneration of the carbon bed.

2.4.4 Control Option 4 - Ultraviolet Curing

Achievable Reductions - The curing chamber is lighted by special lamps such as mercury vapor lights. Some ultraviolet curing lamps in the can industry are water cooled and some air cooled. The air cooled systems exhaust at about 3000 scfm. These ultraviolet curable coatings are specially formulated to cure in the presence of ultraviolet light. These coatings although totally organic, may be considered the equivalent of near zero percent solids since little vaporization takes place during the near instantaneous curing. Theoretically, up to 100 percent reduction of organic emissions is achievable when using ultraviolet curing technology, however, there may be some volatilization of low molecular weight compounds during the curing process. The amount emitted will depend on the coating formulation. In addition, ozone generated by the lamps, is also emitted. (The ozone concentration will likely never exceed 1 ppm in the exhaust air for the ultraviolet systems in the can industry.)[12] Rapid curing, which can take place in less than one second, make the process attractive for high speed can coating operations.[13]

Technical Analyses

Ultraviolet curing technology is becoming more attractive to the can industry partially due to natural gas shortages. Ultraviolet curing technology was first applied on sheet coating lines to dry the first two colors (set) of ink quickly such that another two colors of ink could be applied in the same pass, thereby eliminating the need for oven drying the first set. Research efforts report some progress in ultraviolet curing of the exterior base coat, the inks and the overvarnish in a single pass, followed sometimes by oven baking the coatings to achieve the desired coating film properties. This would not only eliminate individual oven baking of the base coat and inks, but would also eliminate almost all organic emissions from the oven since all the coatings would be ultraviolet sensitive and set before entering the oven.[12,13,14]

Ultraviolet light curing technology is also being considered and in some cases used on a limited basis in other areas of the can industry such as the curing of the exterior of two-piece beer and beverage cans. Progress in the acceptance of ultraviolet coatings for can interiors will likely be slow because each must await Federal Food and Drug Administration approval before they can be used.

For further technical details on ultraviolet curing, see Volume I section 3.3.8 of this series.

Cost of Control Options - The cost of ultraviolet curable coatings is about twice as much as conventional coatings because their use is not widespread, and the chemistry of ultraviolet coatings is more complex. On the other hand, ultraviolet curing reduces energy usage by 60 percent. The cost of curing equipment for ultraviolet coatings is about one-fifth that of conventional ovens. The line speed for ultraviolet curing is comparable to if not greater than that for conventional coating.[15]

Effects and Limitations - Ultraviolet curing technology is presently limited to thin semi-transparent coating films although they are being tested for additional uses in the can coating industry. There are, however, coating applications (such as some can interiors) that will require a matter of years before acceptable ultraviolet curable coatings are available.

2.5 Comparison of Control Options and Conclusions

Incineration is a proven retrofit control system that can reduce organic solvent emissions from can coating facilities. Although incineration can require significant amounts of fuel, installation of primary and secondary heat recovery systems when feasible, will significantly reduce, if not eliminate the incremental energy requirements.

Water-borne, high-solids, powder and ultraviolet curable coatings can reduce organic solvent emissions to the same degree as incineration and may use less energy than solvent-borne coatings. Conversion to water-borne, high-solids, powder and ultraviolet curable coatings has been successful on some can coating formulations; however, many coatings are still in the development stages or are undergoing tests for Food and Drug

Administration and the packaging customer approval. The ability to convert to water-borne, high-solids, powder and ultraviolet curable coatings as a control option will vary from plant to plant depending on the product.

Carbon adsorption can be feasible for reducing organic emissions on the interior body and end spray area and oven, the end sealing compound application area and the side seam spray area. Measures may be needed in some cases to clean the process gas stream first. Because different solvent mixtures are used, the recovered organics may have little market value. However, they can be used as boiler fuel or be incinerated.

Costs of controlling organic emissions from the can coating industry using low solvent coatings is difficult to determine because of the many variable factors in the manufacturing process. Incineration is the most economical retrofit control option when combined with heat recovery. Control costs for carbon adsorption are greater than incineration but approach that of incineration if recovered solvent can be used as fuel.

It may be costly to collect and retrofit add-on control devices to reduce organic emissions from side seam spray coaters, beer and beverage can interior spray coaters and ovens, and the can end sealing compound coaters because 75-100 percent of the organic solvent vapors are now emitted as fugitive emissions within the plant. Conversion to water-borne, high-solids or powder coatings is the best control option for those systems. Moreover, conversion to water-borne, high-solids, powder or ultraviolet curable coatings for the two-piece can coating lines and the sheet coating lines would be the economical options if acceptable. Otherwise, incineration (with heat recovery) or carbon adsorption (with solvent recovery for fuel) is recommended.

If incineration or carbon adsorption is used to reduce emissions, the coater can either be covered with a hood which is ducted to the oven exhaust stream or the coater may be enclosed up to the oven entrance so that the coater emissions are drawn directly into the oven.

The control of organic emissions from can coating facilities will most likely require a combination of several control technologies because of the complexity of coatings used and their application, and the economic and energy considerations in any particular plant.

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3.0 COIL COATING

3.1 Summary of Control Technology

Affected facility	Control Option	Percent Reduction
Coil coating line	Thermal incineration	90-98
	Catalytic incineration	90
	Water-borne & high-solids coatings	70-95

Coil coating line consists of the coater(s), the oven(s) and the quench area(s).

3.2 General Discussion

Coil coating is the coating of any flat metal sheet or strip that comes in rolls or coils.[1] The metal is typically roll coated on one or both sides on a continuous production line basis. The metal may also be printed or embossed. The coated metal is slit and fabricated by drawing, stamping, roll-forming, or other shaping operations into finished products to be used for cans, appliances, roof decks, shelving, industrial and residential siding, cameras, culvert stock, cars, gutters, and many other items.

"Toll" and "captive" coaters represent the two basic divisions of the industry. The toll coater is a service coater who accepts orders to coat metal according to his customers' needs and specifications. The captive coater both coats the metal and fabricates the product from the coated metal within the same plant or corporation. Some coil coaters are both captive and toll coaters.

Coil coating plants are typically located near industrial areas to reduce raw material shipping time and cost. About half of the U.S. coil coating plants are located in Pennsylvania, Illinois and Ohio. On an EPA regional basis, Region V comprises about 46 percent of the coil coaters and Region III about 28 percent. Plants vary in size based on the number and the size of the coil coating lines.

Coil coating lines vary in the maximum width of metal they are capable of coating. The lines can coat metal widths ranging from 0.50 to 72 inches and thickness ranges of approximately 0.005 to 0.090 inches. Line speeds can range up to 400 feet per minute with plans to go as high as 800 feet per minute. Some common coil coating line sizes are 18, 26, 48, 54, 60 and 66 inches.

Coil coating line emissions come from the coating area, the preheat and baking zones of the oven, and the quench area. These emissions are mainly volatile organics and other compounds, such as aldehydes, that result from thermal degradation of volatile organics. Emissions from the combustion of natural gas, which is typically used to heat the ovens, are carbon monoxide, unburned fuel, nitrogen oxides, and aldehydes. If fuel oil is used to heat the ovens, sulfur oxides and greater quantities of nitrogen oxides, and particulates may also be emitted.[2]

The major emissions from a typical coil coating operation are summarized in Table 3-1.

TABLE 3-1 EMISSIONS MEASURED FROM AN UNCONTROLLED NATURAL GAS FIRED COIL COATING OPERATION USING SOLVENT-BORNE COATINGS[3]

Pollutant	Amount emitted
Hydrocarbons	1.0 lb/lb of coating applied
Carbon monoxide	1.10 lb/10^3 ft^3 gas fired
Nitrogen oxides (as $N)_2)$	0.20 lb/10^3 ft^3 gas fired
Aldehydes (as formaldehyde)	0.020 lb/lb coating volatiles applied when water quench is used
Aldehydes (as formaldehyde)	0.027 lb/lb coating volatiles applied when air quench is used

3.2.1 Materials Used - The metals coated in the coil coating industry include various aluminum alloys, steel; plated steel; steel alloys; and some zinc, brass and copper.

Some plants may use as many as 900 different coatings, each containing four to ten different solvents, and some use as much as 40,000 gallons of coatings per month. Approximate weight percentages of volatiles in coatings most often applied in the coil coating industry are shown in Table 3-2.

TABLE 3-2 COATINGS USED IN COIL COATING[4,5]

Coatings	Volatile (weight percent)
Acrylics	40-45
Adhesives	70-80
Alkyds	50-70
Epoxies	45-70
Fluorocarbons	55-60
Organosols	10-15
Phenolics	45-50
Plastisols	0-50
Polyesters	45-50
Silicones	35-50
Vinyls	60-75
Zincromet (TM)	-
Dacromet (TM)	-

The solvents most often used in the coil coating industry include xylene, toluene, methyl ethyl ketone, Cellosolve Acetate (TM), butanol, diacetone alcohol, Cellosolve (TM), Butyl Cellosolve (TM), Solvesso 100 and 150 (TM), isophorone, butyl carbinol, mineral spirits, ethanol, nitropropane, tetrahydrofuran, Panasolve (TM), methyl isobutyl ketone, Hisol 100 (TM), Tenneco T-125 TM), isopropanol and di isoamyl ketone.

3.2.2 Processes and Affected Facilities - Configurations of coil coating lines differ from one another. On some lines, the metal is uncoiled at one end of the line and recoiled at the opposite end. On other lines, called "wrap around" lines, the metal is uncoiled and recoiled at about the same point on the line. Some coil coating lines have a single coater and one curing or baking oven; others called "tandem" lines, have several successive coaters each followed by an oven so that several different coatings may be applied in a single pass. Figure 3-1 is a schematic of a "tandem" coil coating line.

The metal on the coil coating line is moved through the line by power-driven rollers. It is uncoiled as the process begins and goes through a splicer, which joins one coil of metal to the end of another coil for continuous, nonstop production. The metal is then accumulated so that during a splicing operation, the accumulator rollers can descend to provide a continuous flow of metal throughout the line. The metal is cleaned at temperatures of 120°F to 160°F, brushed, and rinsed to remove dirt, mill scale, grease, and rust before coating begins. The metal is then treated for corrosion protection and for proper coating adhesion with various pretreatments,depending on the type of metal being coated and the type of coatings applied.

The first or "prime" coat may be applied on one or both sides of the metal by a set of three or more power-driven rollers. The "pick-up" roll, partially immersed in the coating, transfers the coating to the applicator roll. The metal is coated as it passes between the applicator roll and the large back-up roll. The metal is typically reverse roll coated.

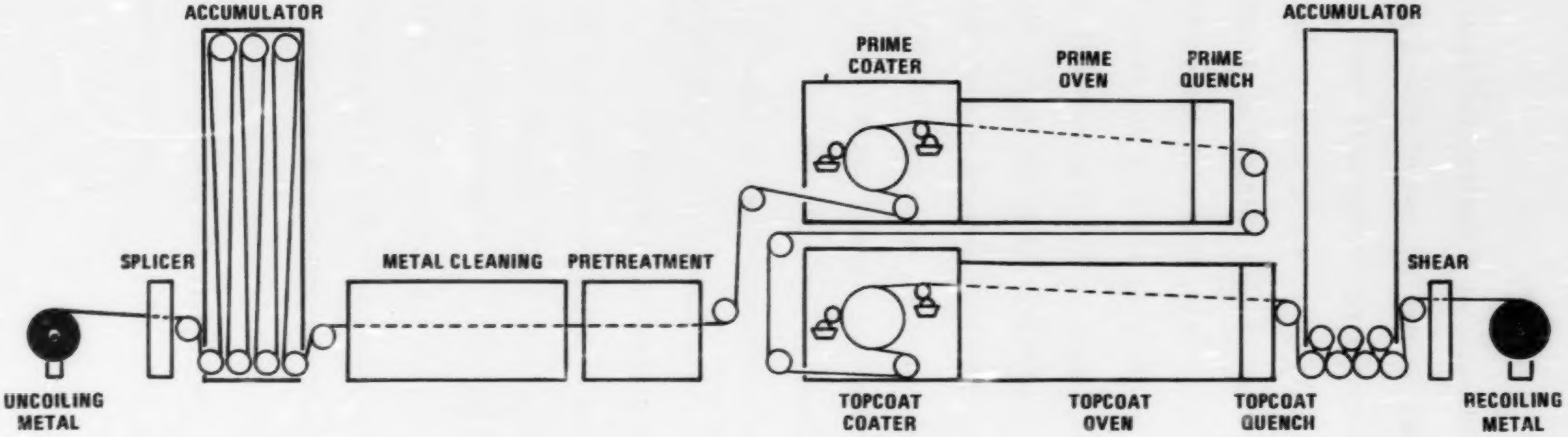
ACCUMULATOR
PRIME COATER
PRIME OVEN
PRIME QUENCH
ACCUMULATOR
SPLICER
METAL CLEANING
PRETREATMENT
SHEAR
UNCOILING METAL
TOPCOAT COATER
TOPCOAT OVEN
TOPCOAT QUENCH
RECOILING METAL

Figure 3-1. Diagram of coil coating line.

Figure 3-2 is a schematic of a typical rollcoater. A third roll, called a "doctor" roll, may be used to control film thickness when applying a high viscosity coating, by making contact with the "pick-up" roll.

The applied coating is usually dried or baked in continuous, multi-zone, high production catenary, flotation, or double-pass oven. The temperatures of the preheat, drying or baking zones may range from 100°F to 1000°F depending on the type and film thickness of coating used, and the type of metal being coated. The flow rates of the ovens' exhaust may vary from approximately 4000 scfm to 26,000 scfm. Many of these ovens are designed for operation at 25 percent of the room-temperature lower explosive level when coating at rated solvent input. As the metal exits the oven, it is cooled in a quench chamber by either a spray of water or a blast of air followed by water cooling.[7]

A second coat or "topcoat" may be applied and cured in a manner similar to the prime coat. The topcoat oven, however, is usually longer than the prime coat oven and contains more zones.

Another method of applying a prime coat on aluminum coils or a single coat on steel coils is to electrodeposit a water-borne coating to either one or both sides of the coil. The coil enters a V-shaped electrocoating bath that contains a roll on the bottom. As the metal goes around the roll, electrodes on each side can be activated and permit the coagulation of the paint particles on either one or both surfaces of the coil. The coated coil is then rinsed and wiped by squeegees to remove the water and excess paint particles. For steel coils, the electrodeposited coating must be baked in an oven. For aluminum coils, however, the prime coat is stable enough to

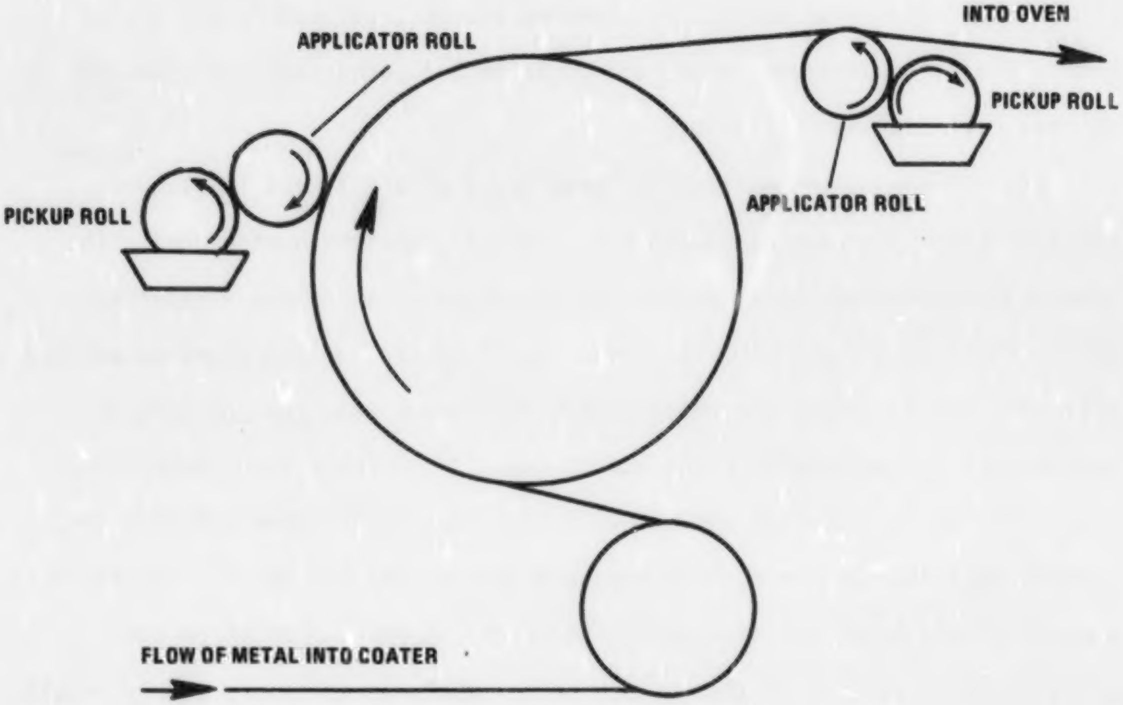
INTO OVEN
APPLICATOR ROLL
PICKUP ROLL
PICKUP ROLL
APPLICATOR ROLL
FLOW OF METAL INTO COATER

Figure 3-2. Typical reverse roll coater.

immediately go over rolls to the topcoat coater without destroying the finish, and then be baked as a two-coat system.[6]

After cooling, the coated metal passes through another accumulator, is sheared at the spliced section, usually waxed, and finally recoiled. The accumulator rolls rise during the shearing process, collecting the coated metal to ensure continuous production. Table 3-3 summarizes the operation of typical coil coating facilities.

Organic vapors are emitted in three areas of a coil coating line: the area where the coating is applied, the oven, and the quench area. The oven emits approximately 90 percent of the organic vapors and a majority of the other pollutants. Of the remaining 10 percent of hydrocarbons emitted, approximately 8 percent are emitted from the coater area and approximately two percent are emitted from the quench area.[3,7] Organic vapor emissions from a tested uncontrolled coil coating facility, reported as methane, are: coater area 480 ppm; oven, 4950 ppm; and quench area 100 ppm."[7] Considerable amounts of aldehydes are also emitted from the thermal degradation and oxidation of volatiles in the ovens. Carbon monoxide emissions mainly result from improper adjustments of oven burners.[3]

3.3 Special Considerations - The coil coating industry has exhibited about 15 percent annual growth rate over the past decade compared with the 4 to 5 percent annual growth rate for most other industrial coating industries.[8,9] The reasons for this rapid growth include the high speed at which the metal may be coated, the low labor costs, the small amount of waste that occurs during the coating process, the uniformity of film thickness (although the range of thickness that can be applied may be limited), the savings on plant space, the wide variety of coatings and designs available, and the short changeover times needed when changing coatings.[9]

TABLE 3-3 OPERATION OF TYPICAL COIL COATING FACILITIES

Line Size (in width)	Ovens	Flow Rate scfm	Temperature°F	Operating solvent concentration (in % LEL)	Type of fuel used	Control Method
18 inch	Prime Topcoat	4,900 3,400	600	10-20 10-20	Natural gas	NONE
26 inch	Prime Topcoat	7,400 12,000	700 700	25 and less	Natural gas	Thermal incineration
31 inch	Single	5,000	Zoned at 400-600	Near 25	Natural gas	Going water-borne
31 inch	Single	5,600	Zoned at 300-600	25 and less	Electric	Plan on going to water-borne
48 inch	Prime Topcoat	25,900 11,700	900-1100 725	25 and less	Natural gas	Catalytic incinerator
54 inch	Prime Topcoat	6,500 12,500	Zoned at 300-600	Near 25	Electric and gas	Plan on going to water-borne
54 inch	Prime Topcoat	24,000 24,000	750 775	10-15 15-25	Natural gas	Thermal incineration
60 inch	Prime Topcoat	26,000	600	Near 25	Natural gas	Thermal incineration
60 inch	Prime Topcoat	35,000	Zoned at 300-800	25 and less	Natural gas	Thermal incineration
66 inch	Prime Topcoat	24,000 24,000		Less than 25	Propane	Thermal incineration on each oven

The captive coil coater, because he fabricates his own product, tends to have more control over the coatings used than the toll coater, who must meet the needs and specifications of customers. New uses for coil coated metal are being found continuously as are new coatings.[10]

Because of the different post-forming operations that coated coils must undergo, coatings must survive many "acceptance tests", including adhesion, impact resistance, film thickness, color, sheen, gloss, hardness and resistance to salt spray and abrasion.[4] Approximately 65 percent of the coil coated production is used by the building industry: therefore, the coatings often must be resistant to weathering, must provide durable finishes, and must satisfy a product warranty.[10] Extensive testing (as long as 5 years) may be required before a coating can be commercialized.[6]

Natural gas is the primary fuel used in coil coating, and propane is the primary backup fuel during curtailments of natural gas or where natural gas is not available. The coil coating industry consumes less than 1 percent of the U.S. total gas usage. Production has been curtailed in some plants because of the shortages of natural gas and the lack of availability of propane as backup fuel.[11] In some areas of the country, the gas companies are not accepting new orders of natural gas. This, coupled with increasing demands for propane are causing some coil coaters to use other forms of fuel such as oil and electricity to heat the ovens, or oil to fire the incinerators. Others are looking into more efficient methods of baking.

The coil coaters typically try to operate the ovens around 25 percent of the lower explosive limit (LEL) as permitted by the insurance companies. Some are permitted to operate at higher LEL's under special conditions and reliable LEL monitoring equipment. However, present LEL monitoring equipment reportedly requires a high degree of maintenance because condensate fouls the sensing device.[4]

It is not always possible to operate at a high LEL. Coil coaters are not always able to vary the exhaust flow rates dynamically from each oven to maintain high LEL's at a given line speed when applying a two-coat system.[12]

On some coil coating lines, the coater is isolated in a room. Since the oven is maintained at negative pressure, the organic vapors from the coater room are pulled into the oven. Others have hoods over the coater to exhaust the organic vapors into the atmosphere.[6]

Coil coaters are also faced with controlling the water pollution from their metal cleaning operations. Many have been required to install water treatment systems and have faced the associated sludge disposal problems. Thus, coil coaters are faced with water pollution control and solid waste disposal costs as well as those of air pollution control.[4]

3.4 Available Control Technology - The following discusses incineration, water-borne and high-solids coatings, all of which reduce organic vapor emissions. Other technically feasible control options may be used on coil coating lines that coat metal for a specific purpose, but they are not yet applicable to the industry as a whole.

Electrostatically sprayed powder coating is limited because a complete selection of acceptable resins is not yet available for use in the coil industry, and the present application technology cannot adequately control film thickness and edge overlap.

The use of electron beam curing is limited because coating formulations have not yet been developed to satisfy the requirements of the coil coating industry. The deficiencies may be related to the chemistry presently used for these coating formulations.[12] Ultraviolet curing is limited because it is presently restricted to thin semi-transparent coatings. Moreover, an acceptable variety of such coatings has not yet been developed for use by the coil coating industry.

The use of carbon adsorption is limited because the high oven discharge temperatures necessitate a large degree of cooling upstream of the adsorber. Further pretreatment would be required because cracking and polymerization of organics form condensable products that can foul or poison the adsorbent. (Pretreatment by water scrubbing may produce a potential water pollution problem). Moreover, even after pretreatment by scrubbing or filtering, some products may still foul the carbon bed, resulting in an inefficient collection of organic vapors. In addition, there would be little market value for solvents recovered by this industry because of the mixtures of solvents used and the expense required to separate them.

Carbon adsorption may be applicable to certain coil coaters who operate low temperature ovens and use uniform coating formulations. However, because the industry is finding new uses for coated coil as well as new coatings that may poison the carbon, adsorption is not widely applicable, especially for independent coil coating operations. If carbon adsorption is considered, it is advisable to analyze the gaseous and condensable organics in the gas stream vented from the ovens to assure such control is practical. For further details on carbon adsorption, see Volume I, section 3.2.1 of this series.

3.4.1 Option 1 - Incineration - A reduction of over 90 percent in organic emissions from a coil coating line is achievable using either noncatalytic or catalytic incineration.

Technical Analysis - Catalytic incineration oxidizes organic emissions efficiently at catalyst inlet gas stream temperatures over 500 to 600°F and catalyst outlet gas stream temperatures of 750 to 1000°F.

The platinum catalysts usually used in catalytic incineration can be deactivated by: aging or high temperatures, coating with particulate matter, or poisoning with contaminants. Natural gas or propane is the preferred fuel for preheating the gases (if necessary) because of its cleanliness.

The life of a catalyst on a coil coating line is about 1 to 2 years, depending on the inlet gas stream temperature, on the inlet concentration of organics, and on other pollutants in the gas stream. At higher inlet temperatures and organic concentrations, the temperature rise from combustion of the organic vapors increases; thus, the exit temperature in the catalyst may become too high for normal catalyst life.

The catalyst can be poisoned by certain materials or coated by particulate such as that from siliconized coatings. These will reduce its efficiency if they are not removed effectively ahead of the catalyst bed.

Catalyst efficienct may be monitored by a hydrocarbon analyzer or in terms of temperature rise and pressure drop across the bed. Such routine inspection and periodic cleaning can insure optimum reduction efficiency of volatile organics and possibly a longer catalyst life.

For further technical details on catalytic incineration, refer to Volume I, section 3.3.2 of this series.

Table 3-4 presents a comparison of calculated catalytic incinerator burner requirements for three systems: simple catalytic incineration, catalytic incineration with "primary" heat recovery, (preheat of gases into the incinerator) and catalytic incineration with primary and "secondary" heat

TABLE 3-4 FUEL REQUIREMENTS FOR CATALYTIC INCINERATORS WITH AND WITHOUT HEAT RECOVERY[a]

		Catalytic Incineration no heat recovery		Catalytic Incineration with primary heat recovery			Catalytic Incineration with primary and secondary heat recovery		
% LEL	Gas temperature to catalyst, °F	Fuel Requirements 10^6 Btu/hr		Heat exchanger efficiency, %	Fuel Requirements, 10^6 Btu/hr		Heat exchanger efficiency, %	Heat recovered by secondary heat exchanger, 10^6 Btu/hr	Net fuel rate, 10^6 Btu/hr
		Net	Gross		Net	Gross			
15	600	1.69	1.80	20	0	0	55	5.58	-5.88
25	500	0	0	-	0	0	55	6.76	-6.76

[a] Process gas flow rate of 15,000 scfm; process gas inlet temperature of 500°F

recovery (recovery of heat from the incinerator exhaust for procss heat).

As can be seen from Table 3-4, when the concentration of the gas stream approaches 25 percent of the LEL, and the inlet gas stream temperature to the combustion chamber is maintained at about 500°F, a coil coating line equipped with a catalytic incinerator may use little, if any, additional energy for the operation of the burner, even without primary heat recovery. A primary heat exchanger without a bypass may not save much energy because the efficiency of the heat exchanger is limited by the upper temperature limitations of the catalyst. When catalytic incineration with only 55 percent efficient secondary heat recovery is used, there is a net fuel savings, assuming the recovered heat can be used for process heat.

Coil coating facilities are currently using catalytic incinerators to reduce organic emissions from their surface coating operations.

Technical Analysis: Noncatalytic (Thermal) Incineration - Noncatalytic incinerators will oxidize most organics at temperatures of 1100 to 1250°F. Some organics, however, such as Cellosolves, (TM), toluene and xylene require 1400 to 1500°F incineration temperatures for oxidation. Proper oxidation is also dependent on residence time (usually 0.4 to 0.6 seconds) and sufficient mixing. If noncatalytic incinerators are not maintained at proper oxidation temperatures or residence times, partially oxidized compounds can be formed. Such compounds, in some cases, may be harmful. Noncatalytic incineration may also increase NO_x levels from a source. For further technical details on noncatalytic incineration, refer to Volume I, section 3.2.2 of this series.

As can be seen from Table 3-5, a significant amount of energy is consumed when noncatalytic incineration is used to reduce organic emissions. As the organic concentration of the gas stream increases from 15 percent to 25 percent of the LEL, the burner requirements are reduced by almost

TABLE 3-5 FUEL REQUIREMENTS FOR NONCATALYTIC INCINERATORS WITH AND WITHOUT HEAT RECOVERY[a]

	Noncatalytic Incinerator no heat recovery		Noncatalytic Incinerator with primary heat recovery			Noncatalytic Incinerator with primary and secondary heat recovery		
	Burner Requirements, 10^6 Btu/hr		Heat exchanger efficiency, %	Fuel Requirements, 10^6 Btu/hr		Heat exchanger efficiency, %	Heat recovered by secondary heat exchanger, 10^6 Btu/hr	Net fuel rate, 10^6 Btu/hr
% LEL	Net	Gross		Net	Gross			
15	9.95	10.58	35	3.14	3.36	55	6.12	-2.76
25	5.59	5.95	25	1.5	1.65	55	6.73	-5.23

[a] Process gas flow rate of 15,000 scfm; process gas inlet temperature of 500°F; incinerator temperature of 1,400°F.

50 percent because of the fuel value of organics. The incinerator would have to heat only 60 percent as much gas with no change in fuel value.

Primary heat recovery (preheating the incoming gas into the incinerator) will decrease the burner fuel requirements in the noncatalytic incinerator as shown in Table 3-5. At a gas stream concentration of 15 percent of LEL, the energy usage will decrease by about 30 percent with a 35 percent efficient primary heat exchanger. At 25 percent of LEL concentration, the energy usage will be the minimum required for noncatalytic incineration using only a 25 percent efficient heat exchanger. Installation of both 35 percent efficient primary and 55 percent efficient secondary heat recovery system will result in a net fuel savings if all the recovered heat is used as process heat. Greater heat exchanger efficiencies will result in even greater fuel savings.

Many coil coating facilities have successfully used either retrofit or integrated noncatalytic incinerators and both primary and secondary heat recovery systems.

Cost of Control Option - Table 3-6 provides a comparison of estimated annual operating costs and operating costs per ton of emissions removed by incineration alone and with various degrees of heat recovery, providing sufficient recovered energy can be used. Operating costs are based on an assumed inlet process temperature of 500°F. For further details on the cost of controlling organic vapor emissions with noncatalytic and catalytic incineration, see section 4 of Volume I of this series.

The operating costs for a coil coating facility using incineration will decrease as the organic concentration increases, and as more energy is recovered from the incinerators to be used for other energy-using processes, as can be seen from Table 3-6. The difference in operating

TABLE 3-6 COMPARISON OF ESTIMATED ANNUAL OPERATING COST FOR COIL COATING INCINERATION[13] [a]

Type of Incineration	Annual Operating Cost at 15% LEL, dollars	Operating Cost per ton of organics removed at 15% LEL, dollars/ton	Annual operating cost per year at 25% LEL dollars	Operating cost per ton of organics removed at 25% LEL, dollars/ton
Noncatalytic, no heat recovery	122,580	153	85,540	71
Noncatalytic, primary heat recovery, only	74,100	93	61,100	51
Noncatalytic, primary and secondary heat recovery	34,800	44	16,910	14
Catalytic, no heat recovery	78,850	98	64,450	54
Catalytic, primary heat recovery only	75,030	94	not applicable	not applicable
Catalytic, primary and secondary heat recovery	39,690	50	"	"
Catalytic, secondary heat recovery only	42,710	53	19,670	16

[a] Process gas flow rate of 15,000 scfm at 500°F, 4,000 hr/yr operating time, $\$2.00/10^6$ BTU fuel cost, tube and shell heat exchangers.

costs for catalytic incinerators with and without primary heat recovery is minimal provided that organics constitute at least 15 percent of the LEL and oven exhaust temperatures are at least 500°F.

For noncatalytic incineration, the smallest annualized operating cost is realized when both primary and secondary heat recovery are used. Catalytic incineration without heat recovery was found to have lower annualized operating cost than noncatalytic incineration without heat recovery.

If the energy can be recovered and used, incineration with heat - recovery can reduce net energy consumption compared to a line without an incinerator. The value of this recovered energy does not, however, completely compensate for other operating costs, and incineration will invariably increase overall operating costs. In addition, there is 40 percent more gas to be treated for a given solvent amount, with resultant increased capital cost, at 15 percent of the LEL than at the same plant at 25 percent of the LEL.

These costs did not include enclosing the coater area or installing hoods to duct the coater exhaust into the oven exhaust. Also, these costs were based on an "ideal" facility where the cost of installation was about 40 percent of the cost of equipment. The degree of difficulty of retrofitting an incinerator to an existing facility will likely increase the installation and engineering costs, therefore, increasing the cost per ton of organics removed.

Effects and Limitations -Adverse environmental effects from incinerators are mostly dependent on the compounds present in the inlet gas stream. If sulfur compounds are present in the inlet gas stream or in the fuel, their oxides will be generated; if halogens are present, their acids may be formed. Also, nitrogen oxides are generated from the nitrogen present in the gas stream.

Some of the particulates found in the gas stream, for example, from siliconized coatings may corrode or foul the heat exchanger tubes. If the incinerator is not preheated before the operation begins, condensate and other particulate matter formed in the tubes during shutdown may ignite and warp the heat exchanger. In addition, catalytic incineration may have limitations because of catalyst poisoning from some coatings used in the coil coating industry.

It was assumed in the cost and fuel usage calculation that the exhaust from both the prime and topcoat ovens is ducted to one incinerator. Actual solvent input into an incinerator will rarely exceed 85 percent of the operating time of a coil coating line due to coating and color changes, running out a coil of rejected metal, etc. During this time, the ovens and incinerator must be maintained at operating temperatures.[12] In addition, it is difficult to maintain an optimum percentage of the LEL exhaust from each oven. The concentrations can vary with compositions of the primer and topcoat, film thickness and line speed. At higher LEL's high heat exchanger efficiencies can cause the incinerator to exceed its design temperature limits. To minimize fuel usage, the primary heat exchanger should be designed to handle such varying concentrations, i.e., to maximize the heat exchanger efficiency as the solvent input decreases and lower the efficiency as the solvent input increases. One method of achieving this is to design a bypass around the heat exchanger. To optimize investment and minimize fuel usage and operating costs, each coil coating operation should be studied individually to determine the most effective heat exchanger efficiency. However, the coil coater will still have to base the choice of an incinerator with optimum heat exchanger efficiency on the most critical situation.

The use of tube and shell heat exchangers was assumed in the cost calculations. There are, however, other types of heat exchangers used by the coil coaters. These heat exchangers will vary in net efficiencies and in cost; and include the rotating ceramic wheel, packed ceramic beds, air to liquid heat exchangers and some others. In addition, there are other methods of operating ovens and incinerators to achieve optimum heat recovery and fuel savings such as; inert atmosphere baking systems with rich fume incinerators, and the recycling of solvent rich exhaust through zoned incinerators.

3.4.2 Option 2 - Water-Borne and High-Solid Coatings

Achievable Reduction - Water-borne coatings are defined as coatings that contain a polymer or resin base, water and often some organic solvent or "cosolvent" that is miscible with water. The presence of a certain percentage of organic solvents in water-borne coatings is necessary to improve stability, appearance, reduce the "orange-peel" effect, depress foaming and improve edge-pull.[14] Water-borne coatings typically used in coil coating are water-soluble coatings.

High-solids coatings contain a solid composition up to 70 or 80 percent by volume. The remaining portion is organic solvent necessary for proper application and optimum curing characteristics.

Table 3-7 lists the potential percentage reduction, in pounds of organic solvent per unit volume of coating, which could be realized by converting to water-borne and high-solids coatings.

TABLE 3-7 POTENTIAL REDUCTIONS FROM USE OF WATER BORNE AND HIGH SOLIDS COIL COATINGS

Coating formulation (by volume)	Pounds of organic solvent per gallon of coating (minus water)	Potential reduction by using water-borne coatings, percent
Water-borne 32% solids 54.4% water 13.6% organic solvents	2.2	--
Organic solvent-borne 20% solids 80% solvent	5.9	90
50% solids 50% solvent	3.7	58
70% solids 30% solvent	2.2	0

Technical Analysis - Water-borne and high-solids coatings are easily applicable with roller coating systems because they have application characteristics similar to organic solvent borne coatings. Converting to these coatings, however, could present some difficulties.

High-solids coatings are difficult to apply due to high viscosity and may necessitate heating of the rolls to reduce the viscosity. This may cause a build-up of resin in the rolls unless a three-roll roller coating system is used. Progress is being made in commercializing medium high to high-solids coatings for the coil coating industry.

Water-borne coatings have different flow and wetting properties from solvent-borne coatings. Evaporation of water from an applied coating cannot be controlled as well as from a solvent mixture. Sometimes coil coating line speeds must be reduced to avoid popping of the film.

Care must be taken to thoroughly clean the metal prior to coating because any grease will result in lack of adhesion and edge-covering, and formation of craters. Also, care must be taken in using certain pre-treatments, such as chromic acid, that may cause water-borne coatings to gel.[14]

Tubes, shafts, bearings and other movable parts on a coater must be replaced or somehow protected from the water-borne coating to avoid corrosion. In addition, all the pipes and pumps must be replaced with non-corrosive materials if the coating is pumped from a separate storage or mixing area. However, since there exists little fire hazard with water-borne coatings, it is possible to use "tote-bins" inside the plant.

Cleaning dried water-borne coatings is difficult because they do not remain soluble in their carrier. Water-borne coatings are difficult to dispose of, and are difficult to transport and store during the winter and summer months.[6]

Electrodeposited water-borne coatings have been successfully applied on aluminum and some steel coils. The electrodeposited coated steel is baked directly after application of the coating. The electrodeposited coated aluminum can be coated immediately with a topcoat then baked in an oven. This system not only reduces volatile organic emissions but also the fuel usage and the costs of a prime coat oven.

For further details on water-borne and high-solids coatings, see Volume I, section 3.3.1 and 3.3.2 respectively, of this series.

Cost of Control Option - The cost of converting to water-borne or high-solids coatings will vary from plant to plant. Some secondary costs will result from the necessity to test the coating and its performance on the line, during forming and during the use of the end-product. It may also be necessary to alter or adjust the equipment with which the metal is formed into its final shape.

Some water-borne coatings may require higher curing temperatures than organic solvent-borne coatings; however, many do not. Increases in energy may be counteracted by a reduction in air flow through the oven necessary in organic solvent systems to maintain the organic vapor concentration below 25 percent of the LEL. It is estimated that in converting to water-borne coatings, a coil coater may reduce the dilution air by a factor of four, therefore reducing energy consumption by 50 percent.[14]

Water-borne coatings may be more costly than organic solvent borne coatings because industrial consumption is not widespread. With increased consumption, further improvements in water-borne coatings and increasing cost of organic solvents, water-borne coatings may become less expensive than organic solvent-borne coatings.[15] High-solid coatings are generally equal to or more expensive than equivalent high-solvent coatings.

Effects and Limitations - Water-borne primers, backers and some low to medium gloss topcoats that equal the performance of organic solvent borne coatings have been developed for aluminum but have not achieved full line speed in all cases. For other metals, such as steel, the uses are so varied that water-borne coatings have not been developed to provide properties equivalent to all of the present organic solvent-borne coatings and which can withstand all post-forming operations. Some, however, are in the early stages of development, but have not reached commercial status.

Water-borne coatings can contain on the average about 2.2 pounds of volatile organic per gallon of coating (minus water) as applied. Medium high solids coatings can contain on the average of 3.1 pounds per gallon of coating applied (minus water).

3.5 Comparison of Control Options and Conclusions -

Incineration and conversion to water-borne or high-solids coatings appear to be the most reasonable control options for reducing organic emissions from coil coating lines because of the typically high curing temperatures and the various mixtures of organic solvents found in the coatings used by this industry. Incineration, coupled with various types of heat recovery, has been successfully applied to existing coil coating lines. Similarly, water-borne coatings have been successfully applied, within limits, to several existing coil coating lines. Over 90 percent reduction of organic emissions is achievable with incineration and 70-95 percent reduction is achievable with water-borne coatings, depending on the processes and the solvent level of the original solvent-borne coatings used.

There are limitations on the options from which to choose, Some coatings used in the industry can poison incinerator catalysts. There is a lack of water-borne and high-solids coatings equivalent to organic solvent-borne coatings for many metal uses, especially where resistance to corrosion or wear is critical, where severe forming operations are performed or where a high gloss finish is required. Incineration, especially noncatalytic, will increase the use of natural gas or other fuels if no nearby operations can use the recovered energy.

Operating costs of incineration for each ton of volatile organic compounds removed are reduced by one half when the concentration of volatiles is increased from 15 percent of the LEL to 25 percent of the LEL. Cost per ton removed for noncatalytic incineration could be reduced further if concentrations were increased above 25 percent of the LEL. Such high concentrations, however, for catalytic incinerators would exceed their design temperature limits. If incinerator heat is recovered, costs per ton removed can be reduced by a factor of 2 to 5 depending on the extent of recovery and type of incineration. The most cost effective systems shown in this document are noncatalytic incinerators with both primary and secondary heat recovery and catalytic incinerators with only secondary heat recovery; both oxidizing exhausts at 25 percent of the LEL.

If incineration is chosen as a control option, the coater may be enclosed in a room. Since the ovens are maintained at negative pressure, the volatile organics will be pulled into the oven through the oven opening. A hood may also be installed over the coater area to collect the volatile organics and exhaust them into the incinerator.

There does not appear to be a single best control system for the entire coil coating industry; therefore, each coil coating facility must be considered separately to determine the most applicable system.[7]

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4.0 FABRIC COATING

4.1 Summary of Control Technology

Affected facility	Control system or strategy	Percentage reduction
Coating line	Incineration	95
	Carbon adsorption	90+
	Low solvent coatings	80-100

(A coating line consists of the application area and the drying oven. The application technique may be a roll, knife or rotogravure coater.)

4.2 General Discussion

Fabric coating involves the coating of a textile substrate with a knife or roller spreader to impart properties that are not initially present, such as strength, stability, water or acid repellancy or appearance.[1]

The fabric coating industry is diverse, concentrated in the northeastern and southeastern portions of the United States, with a wide variation in products and plant sizes. The industry consists mainly of small to moderate size plants each of which specializes in a limited product line.

Most of the industrial facilities located in the northeast are old; some are over 40 years of age. (These can be difficult to modify to achieve an air pollution standard.) Plants in this industry, which is highly competitive, are usually located near either the textile raw material producers or industries using the coated fabric.

Coating solutions may be either aqueous or organic base. It is the latter that produces the organic emissions into the atmosphere. It is estimated that 36 x 10^6 kilograms per year (80 x 10^6 lbs per year) are emitted in the United States by the vinyl coated fabric segment of the industry.[2]

Rubber coating of fabrics is also a large scale of solvent emissions, although nationwide emissions from this source are not currently known.

Applications for coated textiles include industrial and electrical tapes, tire cord, utility meter seals, imitation leathers, tarpaulines, shoe material, and upholstery fabrics.

4.2.1 Materials Used - Substrates (textile materials used to support the coating) can be either natural or man-made. Coating of polyvinyl chloride (PVC) substrates is covered in this section.

Coatings include latexes, acrylics, polyvinyl chloride, polyurethanes, and natural and synthetic rubbers.

4.2.2 Processes and Affected Facilities - The coating line is the largest source of solvent emissions in a fabric coating plant, and the most readily controllable. Some coating plants report that over 70 percent of solvents used within the plant are emitted from the coating line. Other plants, especially those involved in vinyl coating, report that only 40 to 60 percent of solvents purchased by the plant are emitted from the coating line.[3] Remaining solvents are lost as fugitive emissions from other stages of processing and in cleanup. These fugitive losses are generated by:

1. Transfer from rail cars or tank trucks to storage tanks, and subsequent transfer to processing tanks.
2. Breathing losses from vents on storage tanks.
3. Agitation of mixing tanks which are vented to the atmosphere.
4. Solvent evaporation from clean up of the coating applicator when coating color or type is changed.

5. Handling, storage and disposal of solvent soaked cleaning rags.
6. Waste ink disposal. Waste ink is usually distilled to recover much of solvent. After distillation the sludge, which still contains some solvent, is usually dumped in a landfill.
7. Losses from drums used to store coatings which are being pumped onto coating applicator. These are usually 55 gallon drums which are not hooded and may not even be covered.
8. Cleaning of empty coating drums with solvent.
9. Cleaning coating lines with solvent.
10. Evaporation of solvent from the coated fabric after it leaves the coating line. From two to three percent of total plant solvent usage remains in the product. Half of this may eventually evaporate into the air.

Control techniques for the above types of sources include tightly fitting covers for open tanks, collection hoods for areas where solvent is used for clean up, and closed containers for solvent wiping cloths.

Figure 4-1 shows a general outline of a fabric coating operations. The following discussions describe these operations and control options for the coating line.

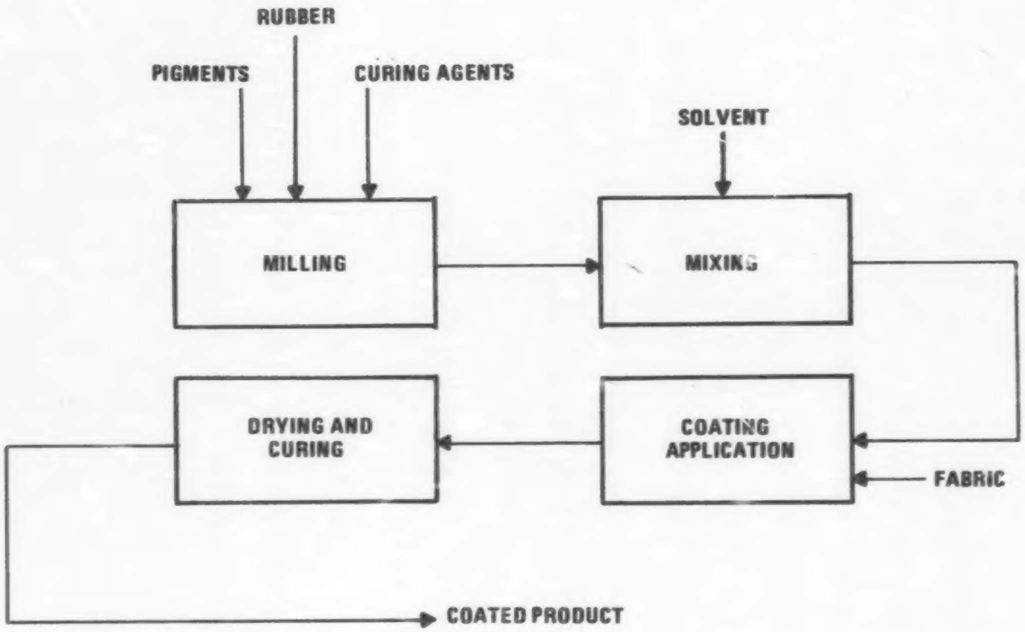
RUBBER
PIGMENTS
CURING AGENTS
SOLVENT
MILLING
MIXING
DRYING AND CURING
COATING APPLICATION
FABRIC
COATED PRODUCT

Figure 4-1. Typical fabric coating operation.

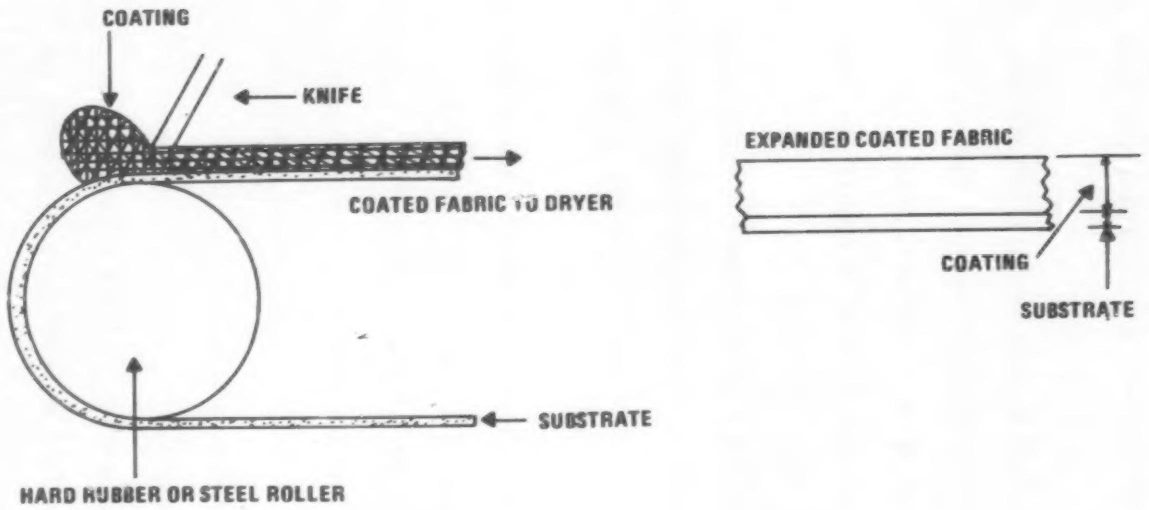
COATING
KNIFE
COATED FABRIC TO DRYER
SUBSTRATE
HARD RUBBER OR STEEL ROLLER
EXPANDED COATED FABRIC
COATING
SUBSTRATE

Figure 4-2. Knife coating of fabric.[1]

Milling - Milling is primarily restricted to coatings containing rubber. Natural and synthetic rubbers are usually milled with pigments, curing agents, and fillers to produce a homogeneous mass that can be dissolved in a suitable solvent. Organic solvents are not usually involved in the milling process; thus, there are seldom any organic emissions from this operation.

Mixing - Mixing is the dissolution of solids from the milling process in a solvent. The formulation is usually mixed at ambient temperatures. Sometimes only small fugitive emissions occur. However, some vinyl coaters estimate that as much as 25 percent of plant solvents are lost in mixing operations.

Spreading or coating - Fabric is usually coated by either a knife or a roller coater. Both methods are basically spreading techniques used for high speed application of coatings to flat surfaces. In some unique situations, dip coating may be used.

In knife coating, probably the least expensive method, the substrate is held flat by a roller and drawn beneath a knife that spreads the viscous coating evenly over the full width of the fabric. Knife coating may not be appropriate for coating materials such as certain unstable knitgoods,[1] or where a high degree of accuracy in the coating thickness is required. Figure 4-2 illustrates knife coating.

In roller coating, the coating material is applied to the moving fabric, in a direction opposite to the movement of the substrate, by hard rubber or steel rolls. The depth of the coating is determined by the gap between rolls (A and B as shown in Figure 4-3). The coating that is transferred from A to B is then transferred to the substrate

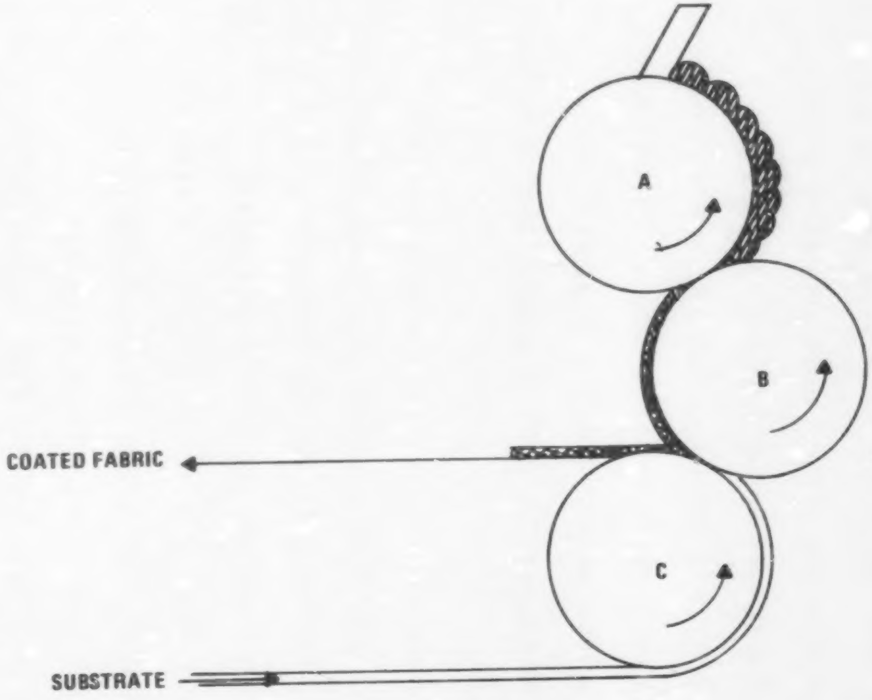
A
B
COATED FABRIC
C
SUBSTRATE

Figure 4-3. Roller coating of fabric.[1]

from roll B. Unlike knife coaters, roller coaters apply a coating of constant thickness without regard to fabric irregularities.

Rotogravure printing is widely used in vinyl coating of fabrics and is a large source of solvent emissions. Rotogravure printing uses a roll coating technique in which the pattern to be printed is etched as a series of thousands of tiny recessed dots on the coating roll. Ink from a reservoir is picked up in these recessed dots and is transferred to the fabric surface. Shadow prints are used to simulate leather grain. A variety of patterns are printed on such items as vinyl wall paper. A transparent protective topcoat over the printed pattern is also applied with rotogravure techniques.

Solvent emissions from the coating applicator account for 25 to 35 percent of all solvent emitted from a coating line. This solvent may be collected by totally enclosing the coating applicator in a small room or booth and sending all booth exhaust to a control device. However, a total enclosure of the coater may be difficult to retrofit on many existing lines. Another alternative is to cover the coater with a hood which can collect most of the solvent emissions.

Drying and Curing - Solvent emissions from the ovens account for 65 to 75 percent of all solvent emitted from a coating line. In most ovens, almost all solvent emissions are captured and vented with exhaust gases. On some coating lines the emissions from the coating applicator hood are ducted to the oven and included with the oven exhaust.

Estimated and reported solvent concentration levels from drying operations range between 5 and 40 percent of the LEL.[4,5,6] Typically drying ovens are designed to process fabric on a continuous basis operating with a web or conveyor feed system. Ovens can be enclosed or semienclosed and, depending on size, may exhaust from a few thousand to tens of thousands of cubic feet per minute of air.[7] Obviously, if an add-on control device is to be installed, it is in the owners best interest to minimize the volume of air which must be treated.

The oven heat increases the evaporation rate of the solvent and, with some coatings, will produce chemical changes within the coating solids to give desired properties to the product. In many cases, evaporation rates are controlled to give the desired properties to the coated fabric.

High air velocities distribute heat uniformly over the fabric surface, facilitate heat transfer to the coating and substrate (by minimizing the laminar zone next to the coated surfaces), and remove the evaporated solvents from the oven at a rate that will prevent their buildup to explosive levels.

Ovens are heated by natural gas, steam, or electricity. Those heated by gas may be either direct or indirect-fired. In the direct-fired oven, the products of combustion are combined with fresh air and circulated over the material. Indirect-fired, steam heated ovens are the most common method for heating most existing facilities, although they are less fuel efficient than direct-fired ovens. They are also limited in the maximum temperature achievable. One advantage of indirect-fired ovens is that the fuel or combustion products cannot contaminate the product. In electrically heated ovens makeup air passes over resistance heaters before exposure to the fabric.

TABLE 4-1 FABRIC AND PAPER COATING OPERATIONS USING CARBON ADSORPTION

Company	Product	Solvent	Exhaust Acfm	Carbon adsorption recovery percent	Operating percent of LEL
Alden Rubber Company	Rubber coated fabric	Toluene	14,000	85	50
Tuck Industries (two plants)	Specialty tapes (fabric and paper)	Toluene	43,000	95	45
Nashua Corporation (two plants)	Specialty tapes (fabric and paper)	Toluene	20,000	85	45 (one)
Dennison Manufacturing Company	Paper		48,000	96	25
Anchor Continental Company	Paper	Toluene	55,000	70	18

Many drying ovens in older plants are only semienclosed. As a consequence they draw in excessive dilution air. Solvent concentrations range between 5 and 12 percent of the LEL according to both calculations and reports by industry. Newer installations are reported to be operating with exhaust concentrations up to 40 percent of the LEL.[4,5]

Levels of up to 50 percent of the LEL are possible if proper safety devices are used according to recent publications. When operating at at 50 percent of the LEL, the total exhaust rate is only one-fifth (20%) of that at 10 percent of the LEL. This greatly reduces the cost of a control system. As shown in Table 4-1, at least three plants in the United States are operated at 40 to 50 percent of LEL.[4,5,8,9,10]

4.3 Special Considerations

The fabric coating industry has a number of unique considerations that affect the technical and economic feasibility of organic emission control. Although a number of the larger facilities specialize in a specific product, many plants produce a variety of products or operate on contract to coat products to a customer's specifications. The latter type, often called "commission coaters", must use a variety of coating formulations to comply with the customer's specifications. The coating may be specified or even supplied by the customer. The variety of coating specifications causes variations in emissions which present problems in designing the control system. Even if the coater knows the solvent compositions, it is necessary to base exhaust volume and controls upon the most critical or difficult situation. The number of solvents used also affects the owner's ability to recover and reuse the solvent. Thus the coating type is an important factor in the cost of controlling emissions from a fabric coating plant. Not only are insurance costs sensitive to the maximum solvent concentration achieved but also the availability and cost of fuel also affect the design and cost of control.

These considerations all emphasize that one must define and specify control technology for many existing plants in the fabric coating industry on a case-by-case basis.

4.4 Available Control Technology

Although few companies have elected to use organic emission controls, there are alternative systems available that are technically feasible. These are carbon adsorption and incineration. Another approach to reducing organic emissions is to switch to lower organic solvent coatings such as aqueous emulsion coatings. These alternatives are discussed in the following sections.

4.4.1 Option 1 - Incineration - Both catalytic and thermal incinerators (afterburners) can destroy 95 percent of the organic emissions introduced to them. Since the effectiveness of the capture and containment system varies from plant to plant, the overall reduction in coating plant emissions may be less than 90 percent.

Technical Analyses - Incinerators convert organic vapors to carbon dioxide and water. They have been used by fabric coaters for a number of years to control volatile organics. A detailed description of incineration is given in Volume I, Section 3.2.2 of this series of reports.

Incinerators can consume large amounts of energy. Fortunately, the heat they generate frequently can be used within the plant. A number of heat recovery schemes are possible including preheating of the incinerator inlet stream (so called primary heat recovery). Another is to transfer the heat from the incinerator exhaust gases to supply process needs (secondary recovery). Primary heat recovery alone can provide approximately 50 percent of the energy necessary to incinerate gases from a typical fabric coating system.[11] If the oven exhaust is operated at greater than 25 percent of the LEL, both primary and secondary heat recovery can actually decrease overall plant fuel requirements. Fabric coaters usually can generate all of their steam requirements with secondary heat recovery. Since the economics of incineration improve with higher solvent concentrations, the cost of modifying an existing system to maximize the concentration of solvent in the oven exhaust must be explored when considering retrofitting a control system. Higher concentrations of solvent also decrease the fuel requirements for the oven. The prospect of future energy shortages, and ever increasing fuel costs will render such modifications of an oven desirable form a cost effectiveness standpoint.

Cost Of Control Options - The cost of installing and operating an incinerator for an exhaust stream of 15,000 scfm at 25 percent of the LEL and 300°F is given in Table 4-2. Note that a noncatalytic incinerator (afterburner) with primary and secondary heat recovery has the lowest annualized operating cost. If the stream is at a lower inlet temperature, more auxiliary fuel would be required and operating costs would be higher. Chapter 4 of Volume I details the assumptions made in calculating these costs. In assessing fuel requirements one must consider that coating operations usually operate intermittently and that greater quantities of fuel are required to start up an incinerator than to operate at steady state.

TABLE 4-2 INCINERATION COSTS FOR A TYPICAL FABRIC COATING OPERATION[a]

Device	Installed cost, $	Annualized cost, $/yr	Control cost $/ton of solvents recovered
Incineration - No heat recovery			
Catalytic	155,000	100,000	51
Noncatalytic (Afterburner)	125,000	105,000	54
Incineration - Primary heat recovery			
Catalytic	180,000	75,000	39
Noncatalytic (Afterburner)	150,000	66,000	34
Incineration - Primary and secondary heat recovery			
Catalytic	220,000	54,000[b]	28[b]
Noncatalytic (Afterburner)	183,000	26,000[b]	13[b]

[a] Process rate of 15,000 scfm; temperature of 300°F, operation at 25 percent of LEL. See Volume I, Chapter 4 for costs for other operating parameters.

[b] Assumes heat is recovered and used.

Effects and Limitations - Energy consumption is a disadvantage of incineration but as discussed both in this Section and in Volume I, recovery of the heat generated can eliminate or minimize the disadvantage.

Other adverse environmental effects are mostly dependent on the compounds present in the inlet gas stream. If nitrogen or sulfur-containing compounds are present in fuel or exhaust gas, their oxides will be generated. Nitrogen oxides will also be generated from oxidation of nitrogen present in the combustion air. If halogens are present, acids will be formed. For a further discussion, see Volume I of this series.

4.4.2 Option 2 - Carbon Adsorption

- A carbon adsorber can remove over 90 percent of the organic vapors from the gases that pass through it. Often collection efficiency across the carbon bed is greater than 95 percent. Just as with the incinerator, the inability to capture 100 percent of the emissions will result in a lower overall plant reduction. Experience has shown that in plants that use activated carbon, the greatest losses occur in handling of solvent. As care is taken to minimize handling losses, the overall solvent recovery increases. It has been reported that 95 percent of the captured solvent vapor can be recovered.[4,10] Table 4-1 identifies some sources that use carbon adsorbers and presents their effectiveness. These companies all have one factor in common: they are able to recycle recovered solvent. The importance of this fact can be seen below under "Cost of Control Option."

Technical Analyses - Activated carbon is used not only by fabric coaters but by a number of industries in a variety of coating applications. Carbon adsorbers are particularly attractive for those sources which use a single solvent or which constantly use the same solvent blend. This permits the owner to recycle the solvent without first purifying the recovered material.

For those plants that must use many solvents or a variety of mixtures, the recovered material would probably have to be distilled. The recovered solvent could, of course, always be used as fuel but its fuel value would always be much lower than its value as a solvent.

Historically, the decision to recover solvent has been based upon cost effectiveness (return on investment) rather than air pollution considerations.

Cost of Control Option - Table 4.3 summarizes installation and operating costs for a 15,000 scfm carbon adsorption unit operating at 170°F and 25 percent of the LEL. Three cases are presented: (1) the solvent has no value, (2) credit at fuel value and (3) credit at replacement value. Notice that only where the recovered solvent can be recycled does the investment pay for itself.

Effects and Limitations - Recovered solvent may be sufficiently water-miscible to pose a water pollution problem if the condensate from the steam is not treated before discharge. This is not likely to be a problem with adsorbers on the discharge stream from most fabric coating ovens. In cases where this problem exists, it can be solved by treating the condensate or incinerating the condensate-solvent stream. One fabric coating operation that uses a water soluble organic solvent is vinyl coating which uses methyl ethyl ketone.

TABLE 4-3 CARBON ADSORPTION COSTS FOR A TYPICAL FABRIC COATING OPERATION[a,b]

	Installed cost, $	Annualized operating cost $/yr	Control cost $/ton of solvents recovered
Case with no credit for recovered solvent	320,000	127,000	72
Case with recovered solvent credited at fuel value	320,000	60,000	34
Case with solvent credited at market chemical value	320,000	(100,000)[c]	(57)[c]

[a] Process rate of 15,000 scfm, temperature of 170°F, operation at 25 percent LEL See Volume I, Chapter 4 for cost for other operating parameters.

[b] See Volume I, Chapter 4 for details on cost estimates

[c] Costs in parenthesis indicate a net gain

4.4.3 Option 3 - Low Organic Solvent Coatings - Organic emissions can be reduced 80 to 100 percent through use of coatings which inherently have low levels of organic solvents. Both high-solids and water-borne coatings are used. The actual reduction achievable depends on the organic solvent contents of the original coating and the new one.

Technical Analyses - Using a coating which has a low organic solvent content may preclude the need for an emission control device. Often the coating equipment and procedures need not be changed when a plant converts to coatings low in organic solvent.

There is only a limited number of cases for which information is available to compare the resulting coating to its organic solvent counterpart. Although a number of companies have converted to low solvent coatings, either in part or in total, one may not presume them to be a universal control measure. Each coating line is somewhat unique and many coated fabrics have different specifications.

Cost of Control Option - The cost of converting to a low organic solvent coating and the cost effectiveness of such a strategy is dependent upon a number of factors. Research and development costs for the coatings may be high and although the unit cost will be lowered as use increases, some users are so specialized that consumption will be small and developmental costs per unit volume will remain high.

4.5 Comparison of Control Options and Conclusions

Each control option discussed in Section 4.4 is a viable alternative and probably the best choice for some sources. The most desirable strategy for all parties concerned is probably the conversion to low solvent coatings. Unfortunately, this option may not be available at present for all situations.

Carbon adsorption and incineration are possible for those sources that cannot use low polluting coatings. Carbon adsorption is probably the most economical for sources that use a single solvent or solvent mixture, but the large capital investment required is appreciably greater than for incineration.

Incineration; preferably with primary and secondary heat recovery, is most applicable at those sources that use a variety of solvents. Fuel costs can be reduced by increasing the organics level in exhaust gases, i.e., by reducing dilution air.

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5.0 PAPER COATING

5.1 Summary of Control Tecnnology

Affected facility	Control technique	Percentage reduction
Coating line	Incineration	95
	Carbon adsorption	90+
	Low solvent coatings	80-99

(A coating line consists of the application area and the drying ovens. The application technique may be a roll, knife or rotogravure coater.)

5.2 General Discussion

Paper is coated for a variety of decorative and functional purposes, using water-borne, organic solvent-borne, or solventless extrusion type materials. Because the organic solvent-borne coating process is a source of hydrocarbon emissions, it is an air pollution concern. Among products that are coated using organic solvents are: adhesive tapes; adhesive labels ; decorated, coated, and glazed paper; book covers; office copier paper (zinc oxide coated); carbon paper; typewriter ribbons; and photographic films.

In organic solvent paper coating, resins are dissolved in an organic solvent or solvent mixture and this solution is applied to a web (continuous roll) of paper. As the coated web is dried, the solvent evaporates and the coating cures. An organic solvent has several advantages: it will dissolve organic resins that are not soluble in water, its components can be changed to control drying rate, and organic base coatings show superior water resistance and better mechanical properties than some types of water-borne coatings. In addition, a large variety of surface textures can be obtained using solvent coatings.[1]

Most organic solvent-borne coating is done by paper converting companies that buy paper from the mills and apply coatings to produce a final product. The paper mills themselves sometimes apply coatings but these are usually water-borne coatings consisting of a pigment such as clay and a binder such as starch or casein.[2] These water-borne coatings are not normally sources of organic emissions.

Most companies that coat paper using organic solvents are listed in the U.S. Department of Commerce's Standard Industrial Classification (SIC) grouping 2641, Paper Coating and Glazing. This group includes establishments primarily engaged in manufacturing of coated, glazed or varnished papers from purchased paper stock.[3] Also included are establishments primarily manufacturing pressure-sensitive tape with backing of any material other than rubber. Establishments primarily engaged in manufacturing carbon paper are classified in Industry Code 3955 and photographic and blue-printed paper in Industry Code 3861. Some type of paper coating with organic solvents, however, may not fall into any of these groups.

The 1967 Census of Manufacturers[4] gives the following information about companies in SIC 2641:

Total employment in industry:	37,100
Number of production employees	27,000
Total plants by geographic region:	
New England	61
Mid-Atlantic	122
North Central	117
South	44
West	53
Total plants in top ten states for paper coating:	
New York	57
California	41
Massachusetts	40
New Jersey	40
Illinois	34
Ohio	27

Pennsylvania	25
Wisconsin	17
Michigan	16
Rhode Island	7

Nationwide emissions of organic solvents from paper coating have been estimated to be 0.56 million tons/year.[5] This estimate includes resin emissions from solventless polyethylene extrusion coatings applied to milk cartons and resin emissions from water emulsion coatings. Also included are solvent emissions from rubber adhesives used to glue paper bags and boxes. A more conservative estimate based on solvent emissions from the type of coating operations found in SIC 2641 is 0.35 million tons/yr. This is slightly less than 2.0 percent of the estimate of 19 million tons/yr of hydrocarbon emissions from all stationary sources reported in Volume I of this series. Manufacturing of pressure sensitive tapes and labels. the largest solvent source in SIC 2641, alone accounts for 0.29 million tons/yr.

Solvent emissions from an individual coating facility will vary with the size and number of coating lines. A plant may have only one or as many as 20 coating lines. Uncontrolled emissions from a single line may vary from 50 to 1000 lbs/hr depending on the line size. The amount of solvent emitted also depends on the number of hours the line operates each day.

Table 5-1 gives typical emission data from various paper coating applications.

TABLE 5-1 EMISSION DATA FROM TYPICAL PAPER COATING PLANTS

Plant	Number of coating lines	Solvent usage, lb/day	Solvent emissions lb/day	Control * efficiency,%	Control device
A	2	10,000	10,000	0	None
B	5	15,000	15,000	0	None
C	8	9,000	9,000	0	None
D	2	1,200	1,200	0	None
E	10	24,000	950	96	Carbon adsorption
F	20	55,000	41,000	90	Carbon adsorption (not all lines controlled)
G	3	5,000	1,500	90	Carbon adsorption
H	3	21,000	840	96	Carbon adsorption
I	1	10,500	500	96	Afterburner

*Neglecting emissions that are not captured in the hooding system.

5.2.1 Materials Used - The formulations usually used in organic solvent-borne paper coatings may be divided into the following classes: film-forming materials, plasticizers, pigments, and solvents. Dozens of organic solvents are used. The major ones are: Toluene, xylene, methyl ethyl ketone, isopropyl alcohol, methanol, acetone, and ethanol.

Although a single solvent is frequently used, often a solvent mixture is necessary to obtain the optimum drying rate. Too rapid drying results in bubbles and an "orange peel" effect in the coating; whereas, longer drying coatings require longer ovens or slower production rates. Variations in the solvent mixture also affect the solvent qualities of the mix.

The main classes of film formers used in paper coating are cellulose derivatives and vinyl resins. The most commonly used cellulose derivative, nitrocellulose has been used for paper coating decorative paper, book covers and similar items since the 1920's. It is relatively easy to formulate and handle, and it dries quickly, allowing lower oven temperatures than vinyl coatings. The most common vinyl resin is the copolymer of vinyl chloride and vinyl acetate. These vinyl copolymers are superior to nitrocellulose in toughness, flexibility and abrasion resistance. They also show good resistance to acids, alkyds, alcohols and greases. Vinyl coatings tend to retain solvent, however, so that comparatively high temperatures are needed. In general, nitrocellulose is most applicable to the decorative paper field, whereas vinyl copolymers are used for functional papers such as some packaging materials.[1]

Plasticizers are often added to a coating to improve its flexibility. Three common plasticizers are dioctyl phthalate, tricresyl phosphate, and castor oil. Each type of resin has an optimum plasticizer concentration. As plasticizer concentration increases, the coating becomes more flexible until it begins to be too soft and tacky.

In the production of pressure sensitive tapes and labels, adhesives and silicone release agents are applied using an organic solvent carrier. The adhesive layer is usually based on one of the following organic solvent-borne resins: natural or synthetic rubber, acrylic or silicone. Because of their low cost, natural and synthetic rubber compounds are the main film formers used for adhesives in pressure sensitive tapes and labels, although acrylic and silicone adhesives offer performance advantages for certain applications.

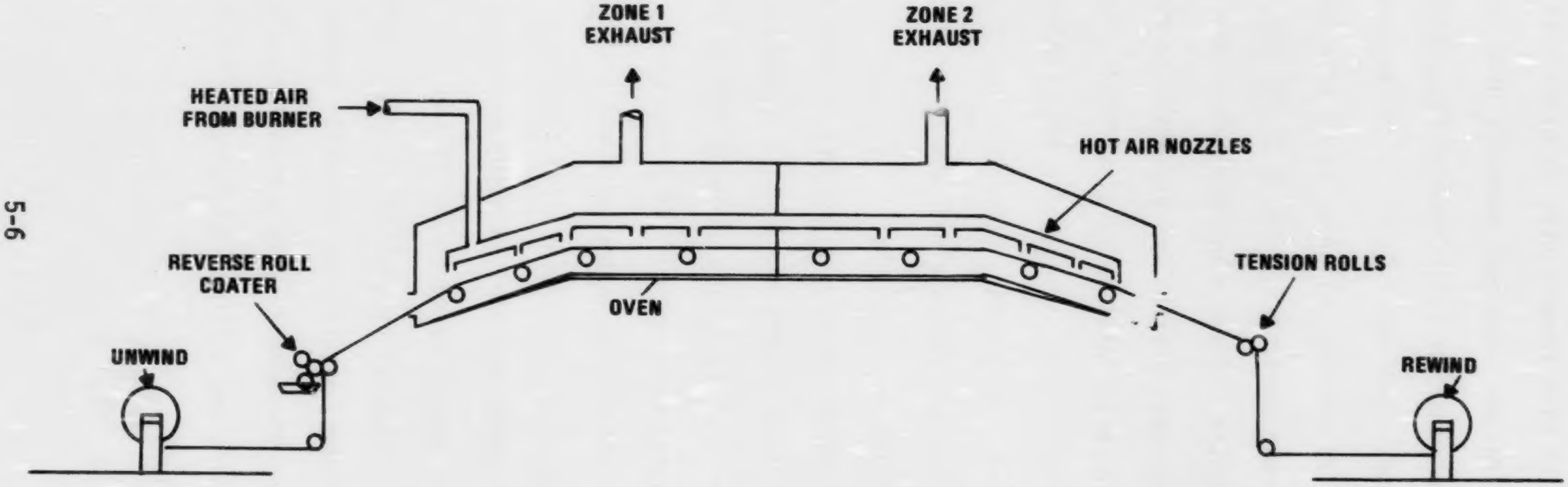
ZONE 1
EXHAUST
ZONE 2
EXHAUST
HEATED AIR
FROM BURNER
HOT AIR NOZZLES
REVERSE ROLL
COATER
OVEN
TENSION ROLLS
UNWIND
REWIND

Figure 5-1. Typical paper coating line.

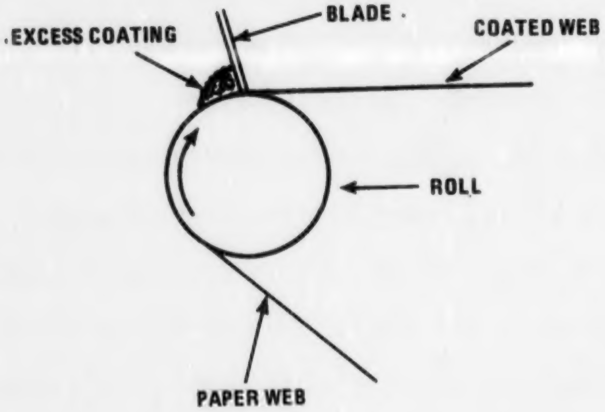
EXCESS COATING
BLADE
COATED WEB
ROLL
PAPER WEB

Figure 5-2. Knife coating of paper.

The paper on which adhesive labels are attached until use are treated with a release agent so that the adhesive tag may be easily removed. This is usually a silicone coating that is applied with a solvent. Release agents are also applied to the backside of pressure sensitive tapes with organic solvents so that the tapes will unwind easily.

5.2.2 Processes and Affected Facilities Figure 5-1 shows a typical paper coating line. Components include an unwind roll, a coating applicator (knife, reverse roll, or gravure), an oven, various tension and chill rolls, and a rewind roll. The unwind, rewind and tension rolls display various degrees of complexity depending on the design of the line.

The coating applicator and the oven are the main areas of organic emission in the paper coating facility.

Coatings may be applied to paper in several ways. The main application devices are knives, reverse rollers, or rotogravure devices.

A knife coater (Figure 5-2) consists of a blade that scrapes off excess coating on the paper. The position of the knife (relative to the paper surface) can be adjusted to control the thickness of the coating. The knife coater is simply constructed and easy to clean.

The reverse roll coater (Figure 5-3), applies a constant thickness of coating to the paper web, usually by means of three rolls -- each rotating in the same direction. A transfer roll picks up the coating solution from a trough and transfers it to a coating roll. (Sometimes there is no transfer roll and the coating is pumped directly onto a coating roll.) A "doctor roll" removes excess material from the coating roll. The gap between the doctor roll and the coating roll determines the thickness of the coating. The web is supported by a rubber backing roll where the coating roll contacts the paper. The coating roll turns in a direction opposite to that of the paper, hence the name "reverse

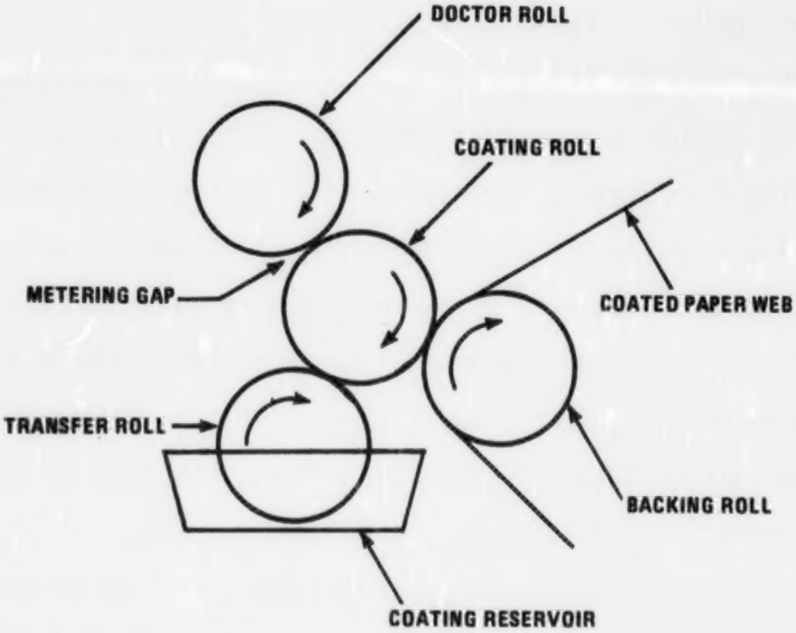
DOCTOR ROLL
COATING ROLL
METERING GAP
COATED PAPER WEB
TRANSFER ROLL
BACKING ROLL
COATING RESERVOIR

Figure 5-3. Four-roll reverse roll coater for paper.

roll". This reverse direction of the coating roll reduces striations in the coating that can form if the coating roll is turned in the same direction as the paper web.

Knife coaters can apply solutions of much higher viscosity than roll coaters, thus less solvent is emitted per pound of coating applied. Knife coaters handle coatings with viscosity up to 10,000 centipose(cp). Reverse roll coaters operate best in a much more dilute range where viscosity is 300 to 1500 cp. Roll coaters, however, can usually operate at higher speeds, and show less tendency to break the paper. Both kinds of coaters apply coatings of good uniformity.[1]

Rotogravure, another type of application method used by paper coaters, is usually considered a printing operation. With it, the image area on the coating or rotogravure roll is recessed relative to the nonimage area. The coating is picked up in the recessed areas of the roll and transferred directly to the substrate. The gravure printer can print patterns or a solid sheet of color on a paper web. Rotogravure can also be used to apply materials such as silicone release coatings for pressure sensitive tapes and labels. Because of the similarities, this study is appropriate for gravure as well as knife and roll coating.

Most solvent emissions from coating paper come from the dryer or oven. Ovens range from 20 to 200 feet in length and may be divided into two to five temperature zones. The first zone, where the coated paper enters the oven, is usually at a low temperature ($\sim$ 110°F). Solvent emissions are highest in this zone. Other zones have progressively higher temperatures that cure the coating after most of the solvent has evaporated. The typical curing temperature is 250°F, although in some ovens temperatures of 400°F are reached. This is generally the maximum because higher temperatures can damage the paper. Exhausts streams from oven zones may be discharged independently to the atmosphere or into a common header, and sent to some type of air pollution control device. The average exhaust temperature is about 200°F.

Oven heaters are either direct or indirect fired. With direct-fired heaters, combustion products contact the coated web inside the oven. The burners themselves may be inside the oven chamber. More commonly, the burners are mounted external to the oven. In this case, heated air (along with products of combustion) is blown directly from the burner to the oven chamber.

Although natural gas is the fuel most often used for direct-fired ovens, fuel oil is sometimes used. Some of the heavier grades of fuel oil can create problems because SO_2 and particulate may contaminate the paper coating. Distillate fuel oil usually can be used satisfactorily.

Indirect-fired oven heaters are arranged so that products of combustion do not enter the oven chamber. A heat exchanger of some type is used to transfer heat from the burner to the oven chamber. Because combustion products do not enter the oven chamber in the indirect-fired heater, there is no chance for contamination of the paper coating, and dirtier fuels can be burned. Fuel is not used as efficienctly in the indirect-fired oven, so more fuel will be required than if direct-firing is used.

Steam produced in gas or oil-fired boilers is sometimes used to heat ovens in the paper industry because paper coating ovens operate at fairly low temperatures. (Such boilers could also burn solvent collected by a carbon adsorption system.) Typically, the steam is piped to the oven, and fresh air drawn into the oven is heated by passing it over the steam coils.

Most paper coaters try to maintain air flow through their ovens so the solvent concentration will be 25 percent of the LEL, although many ovens are run at much lower solvent concentrations. As the energy shortages intensifies, coaters are making greater efforts to minimize dilution air and thus raise solvent concentrations.

Although 25 percent of the LEL is often regarded as the maximum allowable solvent concentration in the oven discharge because of safety considerations, insurance and safety requirements will sometimes permit even higher solvent concentrations. The Handbook of Industrial Loss Prevention notes that flammable vapor concentrations of up to 50 percent of the LEL may be tolerated if approved continuous vapor concentration indicator controllers are used.[6] The controller must sound an alarm when concentrations reach 50 percent, and shut the oven down automatically when concentrations reach 60 percent of the LEL.

Precise methods are available for calculating the amount of dilution air needed to maintain the exhaust solvent concentration at a given LEL level. However, most of the paper-converting industry uses the estimation method of assuming 10,000 ft^3 of fresh air, referred to 70°F, per gallon of solvent evaporated in the oven.[7] This method will give a solvent concentration of approximately 25 percent of LEL for most solvents, but the range may vary from 10 percent to 32 percent of the LEL for some solvents.

The exhaust flow rates from paper coating ovens vary from 5000 to 35,000 scfm depending on size. Average exhaust rates are 10,000 to 20,000 scfm. Paper coating ovens vary in cost depending on web width, line speed, and complexity of coating and associated equipment. For example, some lines have two coating stations so that the paper web may be coated on both sides. Paper coating lines have an installed cost of $100,000 to $1,000,000. A typical line would cost about $300,000.

In a typical paper coating plant about 70 percent of all solvents used are emitted from the coating line. The emphasis in this chapter is on control of the coating line. However, about 30 percent of plant emissions are from the other sources. These include solvent transfer, storage, and mixing operations. In order to control solvent emissions from these areas, provisions must be made to insure that solvent containing vessels have tight fitting covers and are kept closed. Another often overlooked source of solvent loss is use of solvents for cleaning various coatings and sludges from the coating line. This must be done before every color change. Areas of the coating line that are frequently cleaned with solvent can be hooded so that solvent fumes are captured and sent to a control device. Dirty cleanup solvent can be collected, distilled and reused. Solvent soaked wiping rags should be kept in closed containers.

Almost all emissions of the solvent from the coating line itself can be collected and sent to a control device. Many plants report that 96 percent of solvent introduced to the coating line is recovered. Most of the coating line emissions are from the oven and the coating application area. The oven emissions can be exhausted directly to a control device.

Part of the solvent remains with the finished product after it has cured in the oven. For example, certain types of pressure-sensitive tapes have 150 to 2,000 ppm by weight of solvent in the adhesive mass on the finished tape. Some coaters estimate that 2 or 3 percent of solvent remains in the product.

5.3 Special Considerations

The manufacture of photographic film presents special solvent control problems. Four or more layers of coatings may be applied to a photographic film, using equipment and coating techniques similar to those used for other paper coatings. Because the coatings on the photographic film later undergo chemical reactions, the composition and quality of the coatings must be tightly controlled. Because of the nature of these coatings, certain control options may not be practical. For example, it may be impossible to recover solvents in a carbon adsorption unit and then reuse these solvents in new photographic coatings since the reclaimed solvents may contain enough impurities to contaminate the film.

5.4 Available Control Technology

5.4.1 Option 1 - Low Solvent Coatings

Achievable Reductions - These are shown in Table 5-2.

TABLE 5-2 ACHIEVABLE SOLVENT REDUCTIONS USING LOW SOLVENT COATINGS IN PAPER COATING INDUSTRY

Type of low solvent coating	Reduction achievable,%[a]
Water-borne coatings	80-99
Plastisols	95-99
Extrusion coatings	99+
Hot melts	99+
Pressure sensitive adhesives	
Hot melt	99
Water-borne	80-99
Prepolymer	99
Silicone release agents	
Water-borne emulsions	80-99
100 percent nonvolatile coatings	99+

[a] Based on comparison with a conventional coating containing 35 percent solids by volume and 65 percent organic solvent by volume.

Technical Analysis - Low Solvent Paper Coatings - A variety of low solvent coatings have been developed for coating paper. These coatings form organic resin films that can equal the properties exhibited by typical solvent-borne coatings for some uses.

Water-borne coatings have long been used in coating paper to improve printability and gloss. The most widely used types of water-borne coatings consist of an inorganic pigment and nonvolatile adhesive. Such older water borne coatings are useful but cannot compete with organic solvent coatings in properties such as weather , scuff and chemical resistance. Newer water-borne coatings have been developed in which a synthetic insoluble polymer is carried in water as a colloidal dispersion or an emulsion. This a two-phase system in which water is the continuous phase and the polymer resin is the dispersed phase. When the water is evaporated and the coating cured, the polymer forms a film that has properties similar to those obtained from organic solvent based coatings.[1]

Plastisols and organisols are low solvent coatings. Plastisols are a colloidal dispersion of a synthetic resin in a plasticizer. When the plasticizer is heated, the resin particles are solvated by the plasticizer so that they fuse together to form a continuous film. Plastisols usually contain little or no solvent, but sometimes the addition of a filler or pigment will change the viscosity so that organic solvents must be added to obtain desirable flow characteristics. When the volatile content of a plastisol exceeds 5 percent of the total weight, it is referred to as an organisol.

Plastisol technology began in the 1940's and was first applied to cloth; vinyl upholstery in automobiles is an example of a plastisol coating. Paper is coated with plastisols to make products such as artificial leather goods, book covers, carbon paper and components of automobile interiors. Plastisols may be applied by a variety of means, but the most common method is probably reverse roll coating. One advantage of plastisols is that they can be applied in layers up to 1/8 inch thick. This avoids the necessity of multiple passes through a coating machine.

Although organic solvents are not evaporated from plastisols, some of the plasticizer may volatilize in the oven. This plasticizer will condense when emitted from the exhaust stack to form a visible emission. Companies that use plastisols often have a small electrostatic precipitator to remove these droplets from the oven exhaust

Hot melt coatings contain no solvent; the polymer resins are applied in a molten state to the paper surfaces. All the materials deposited on the paper remain as part of the coating. Because the hot melt cools to a solid coating soon after it is applied, a drying oven is not needed to evaporate solvent or to cure the coating. Energy that would have been used to heat an oven and to heat makeup air to replace oven exhaust is therefore saved. Considerable floor space is also saved when an oven is not used. In addition, the paper line speed can be increased because the hot melt coating cools faster than a solvent coating can dry.[1]

One disadvantage with hot melt coatings is that materials that char or burn when heated cannot be applied by hot melt. Other materials will slowly degrade when they are held at the necessary elevated temperatures.

Hot melts may be applied by heated gravure or roll coaters and are usually applied at temperatures from 150°F to 450°F.[1] The lower melting point materials are generally waxy type materials with resins added to increase gloss and hardness. The higher melting point materials form films that have superior scuff resistance, transparency and gloss. These coatings form excellent decorative finishes. One particular advantage of hot melts is that a smooth finish can be applied over a rough textured paper. This is possible because the hot melt does not penetrate into the pores of the paper.

A type of hot melt coating, plastic extrusion coating is a solventless system in which a molten thermoplastic sheet is discharged from a slotted dye onto a substrate of paper, paperboard, or synthetic material. The moving substrate and molten plastic are combined in a nip between a rubber roll and a chill roll. A screw type extruder extrudes the coating at a temperature sometimes as high as 600°F. Low and medium density polyethylene are used for extrusion coating more than any other type resins.[8]

More than 260 extrusion coating lines now produce materials for Paper, paperboard, and flexible packaging applications.[8] Hundreds of products are coated with extrusion coatings. Food packaging materials are often coated by extrusion coatings because a good moisture barrier can be formed. A well known extrusion coated product is the polyethylene-coated milk carton, which became popular in the 1960's. Before that time, milk cartons were coated with wax.

Pressure sensitive adhesives are an area in which low solvent technology is being applied. Because this is a large industry, the potential for solvent emission reduction is great. In 1974, sales of pressure-sensitive adhesives in the United States were over $1 billion, and the growth rate about 15 percent per year. Products using pressure sensitive adhesives include tapes and labels, vinyl wall coverings, and floor tiles. Nationwide organic solvent emissions from pressure sensitive tape and label manufacture is 580 million pounds per year.

The three types of low solvent coatings applicable for use as pressure sensitive adhesives are: hot melts, water-borne systems, and prepolymer systems.

Pressure-sensitive hot melts currently being marketed consist mostly of styrene - butadiene rubber block copolymers. Some acrylic resins are used, but these are more expensive. The capital expense of hot melt coating equipment is a problem for paper coaters that have already invested heavily in conventional solvent coating equipment. There are currently four manufacturers of hot melt coating application equipment for pressure sensitive adhesives.[9]

Water-borne adhesives have the advantage that they can be applied with conventional coating equipment. Water-borne emulsions, which can be applied less expensively than can solvent-borne rubber-based adhesives, are already in use for pressure sensitive labels. A problem with water borne adhesives is that they tend to cause the paper substrate to curl and wrinkle. Some companies have overcome this wrinkle problem, but many smaller companies have not.

Pre-polymer adhesive coatings are applied as a liquid composed of monomers containing no solvent. The monomers are polymerized by either heat or radiation. These pre-polymer systems show promise, but they are presently only in a developmental stage.

Silicone release coatings, usually solvent-borne, are sometimes used for pressure-sensitive, adhesive-coated products. Two low-solvent alternatives are currently on the market. The first is a 100 percent nonvolatile coating which is usually heat-cured, but may be radiation cured. This is a pre-polymer coating which is applied as liquid monomers that are cross-linked by the curing process to form a solid film. The second system is water emulsion coatings.

Products are being developed that will allow solvent recovery from solvent-borne silicone coatings using carbon adsorption. Currently, there are difficulties with recovering solvent from silicone coatings because some silicone is carried into the adsorber where it fouls the carbon and lowers collection efficiency.

TABLE 5-3 CAPITAL COST OF SILICONE COATING SYSTEMS IN PAPER COATING INDUSTRY[10]

Coating systems	Net cost $/lb of silicone solids on paper
Solvent (with solvent recovery)	8.20
Solvent (with solvent incineration)	7.38
Solventless (heat cure)	7.11
Solvent (with no recovery)	6.69
Water emulsion system	5.28

The emulsion system is the lowest in cost, but the 100 percent solventless (pre-polymer) process may prove to be the most practical system in the long run. It may be difficult for paper coaters that are familiar with organic solvent-borne systems to switch to a water-borne system because of wrinkling of the paper and other application problems.

Cost of Control Option - Costs will vary for low solvent systems depending on the type of low solvent coating and the particular end use. The low solvent coatings will be economical once the technology has been established, but there can be large costs involved in initially developing the coatings, purchasing new application equipment and learning to use the new systems.

Cost comparisons between various low solvent coatings are not as easy to make as are cost comparisons between various types of add-on control systems. However, a detailed cost comparison has been made between various types of silicone application systems.[10] This comparison is shown in Table 5-3. The cost of learning to apply water-borne systems to paper could be very large.

Additional costs will be associated with switching to 100 percent nonvolatile (pre-polymer) coatings. Most organic solvent-borne silicone release coatings are currently applied by gravure or reverse roller None of these are suitable for solventless coatings. Solventless coatings must be applied with 3-roll or 4-roll offset gravure presses. These cost from $25,000 to $200,000 per coating line. A cost of $100,000 would be about average. Because of these costs, availability of capital can be an impediment to the adoption of solventless silicone coatings.

Effects and Limitations - Most of the low solvent coatings listed here are currently being used for certain types of products. However, organic solvent-borne coatings have been developed over the course of decades, whereas the low solvent coatings are only now being applied to many products. Continued research will expand the number of applications for these low solvent coatings; however, at present, low solvent coating systems are not available for all paper coating applications.

5.4.2 Option 2--Incineration

Achievable reductions--Thermal (noncatalytic) incinerators may be used to control organic vapors from paper coating operations. Catalytic incinerators, widely used for printing operations, have rarely been applied to control paper coating operations using roll coating or blade coating but certainly are applicable.

Incinerators, if properly operated, can be over 95 percent efficient in controlling organic vapors which are directed to the incinerator. The overall control for the entire plant will be less because of the emissions which escape captured.

Technical analysis--Incinerators have been retrofitted to a large number of oven exhausts from paper coating lines to use primary and even secondary heat recovery. A recent article describes how five paper coating lines for producing office copier paper were fitted with incinerators, which were equipped with ceramic wheel heat exchanger.[11] The recovered heat was used to heat the ovens. Total fuel consumption for the lines actually decreased after the incinerators were installed. For a discussion of the capabilities and limitations of heat recovery, see Section 3.2.2 of Volume I.

Cost of control option--Section 4 of Volume I provides cost data for incineration at various gas flow rates and temperatures. Exhaust rates from typical paper coating ovens range from 8,000 to 20,000 scfm at exhaust temperatures of 175°F to 300°F. Costs for catalytic and noncatalytic incinerators operating on a 15,000 gas stream at 300°F and at 25 percent of the LEL are given in Table 5-4.

TABLE 5-4 INCINERATION COSTS FOR A TYPICAL PAPER COATING OPERATION[a]

Device	Installed cost, $	Annualized cost, $/yr	Control cost, $/ton of solvent burned
Incineration-- No Heat Recovery			
catalytic	155,000	100,000	51
noncatalytic (afterburner)	125,000	105,000	51
Incineration-- Primary Heat Recovery			
catalytic	180,000	75,000	39
noncatalytic (afterburner)	150,000	66,000	34
Incineration-- Primary and Secondary Heat Recovery			
catalytic	220,000	54,000[b]	28[b]
noncatalytic (afterburner)	183,000	26,000[b]	13[b]

[a] Process rate of 15,000 scfm; temperature of 300°F, operation at 25 percent of LEL.

[b] Assuming recovered heat can be used.

Effects and limitations--The major problem associated with the use of afterburners to control organic vapor emissions from paper coating lines is the limited availability of natural gas. If heat recovery is used and the system is operated properly, no additional fuel may be necessary.

Primary heat recovery refers to using the incinerator exhaust to preheat oven gases going to the incinerator. Secondary heat recovery means using heat from the incinerator for plant operations such as heating the oven or for room heating. Thermal (noncatalytic) incinerators can be operated at lowest annual expense if both primary and secondary heat recovery are used. It is possible, however, that the heat recovered from the secondary heat recovery unit cannot be totally utilized at some paper coating plants. Paper coating line ovens operate at relatively low temperatures, usually around 250°F and rarely over 400°F so the heat available to the secondary heat exchanger from the incinerator may be more than needed by the oven. If some other use for the excess heat cannot be found, the full cost savings of secondary heat recovery will not be achieved.

When silicone-release coatings are being applied, silicone compounds may be emitted. These will foul the heat transfer surface of a shell and tube heat exchanger and the heat transfer efficiency will decrease.

5.4.3 Option 3 - Carbon Adsorption

Achievable reductions--Carbon adsorption units can be over 90 percent efficient in controlling organic solvent vapors that are drawn into the carbon bed.

Technical Analysis - Carbon adsorption has been used since the 1930's for collecting solvents emitted from paper coating operations. Most operational systems on paper coating lines were installed because they were profitable. Pollution control has usually been a minor concern. Carbon adsorption systems at existing paper coating plants range in size from 19,000 to 60,000 scfm. Exhausts from several paper coating lines are often manifolded together to permit one carbon adsorption unit to serve several coating lines. Paper products that are now made on carbon-adsorption-controlled lines include pressure sensitive tape, office copier paper, and decorative paper.

Carbon adsorption is most adaptable to single solvent processes. Many coaters using carbon adsorption have reformulated their coatings so that only one solvent is required. Toluene, probably the most widely used solvent for paper coating, is readily captured in carbon adsorption systems.

The greatest obstacle to the economical use of carbon adsorption is that in some cases reusing solvent may be difficult. In many coating formulations, a mixture of several solvents is needed to attain the desired solvency and evaporation rates. If this solvent mixture is recovered, it sometimes cannot be reused in formulating new batches of coatings. Also if different coating lines within the plant use different solvents and are all ducted to one carbon adsorption system, then there may be difficulty reusing the collected solvent mixture. In this case solvents must be separated by distillation.

Separation of solvent mixtures by distillation is well established technology and several plants are already doing this. One paper coating plant has been using such distillation procedures since 1934. Distillation equipment can be expensive, however, and it is hard to build flexibility into a distillation system. Flexibility is needed because many paper coaters, especially those who do custom work for others, are constantly changing solvent formulations.

Cost of Control Option - The cost of using carbon adsorption to control hydrocarbons emissions is outlined generally in Chapter 4, Volume I. The costs for a plant operating with an exhaust of 15,000 scfm of gas at 170°F and 25 percent of LEL are given in Table 5-5

TABLE 5-5 CARBON ADSORPTION COSTS FOR PAPER COATING INDUSTRY[a,b]
(15,000 scfm, 170°F, 25% of LEL)

	Installed cost, $	Annualized cost, $/yr	Control cost, $/ton of solvent recovered
No credit for recovered solvent	320,000	127,000	125
Recovered solvent credited at fuel value	320,000	60,000	40
Solvent credited at market value	320,000	(100,000)[c]	(50)[c]

---

[a] Process rate of 15,000 scfm, temperature of 170°F, operation at 25 percent of LEL.

[b] See Volume I, Chapter 4 for details on cost estimates.

[c] Costs in parenthesis indicate a net gain.

The installed cost given above is for a carbon steel adsorber. Certain solvents such as ketones and ethyl acetate require that the vessel be made of special alloys. These solvents form acids when exposed to steam, and can corrode carbon steel. Stainless steel alloys are normally used in these cases, For materials of other than carbon steel, the cost of equipment increases significantly.

If a distillation unit must be included, the installed cost of the carbon adsorption system will increase significantly. The installed cost of the distillation unit will depend on the number of distillation columns, the complexity of the separation, and the size of the columns. These factors will be determined by the quantity, complexity and physical properties of the solvents to be separated.

An example of distillation costs encountered is the separation of a mixture of 50 percent methyl ethyl ketone (MEK), 25 percent toluene and 25 percent methyl isobutyl ketone (MIBK) into a pure dry MEK stream and a dry toluene - MIBK mixture. The separation system consists of a decanter, neutralizing tank and two distillation columns together with necessary heat exchangers, pumps, structural supports and instrumentation. The system handles a solvent feed rate of 1.5 gallons per minute which corresponds to a coating oven exhaust of 15,000 cfm at solvent concentration of 25 percent of LEL. The cost of this separation system is approximately $125,000 in carbon steel construction.[12]

Impacts and Limitations - The only adverse environmental effect of carbon adsorption is the possibility of small amounts of organic solvent remaining in the water phase after the carbon bed is steam stripped. Water pollution has not been reported as a problem by paper coaters currently using carbon adsorption.

5.5 Comparison of Control Options and Conclusions

The two proven add-on control devices for controlling organic solvent emissions from paper coating lines are incinerators and carbon adsorbers. Both have been retrofitted onto a number of paper coating lines and are being operated successfully.

The main constraint to the use of incinerators is the possible shortage of natural gas. However, in many cases the combination of afterburner and oven will use no more fuel than the oven alone if proper heat recovery is used. Incinerators can be operated on LPG or distillated fuel oil if natural gas is not available.

The major drawback to the use of carbon adsorption is that in some cases solvent mixtures may not be economically recoverable in usable form. If the recovered solvent has no value, it is more economical to incinerate and recover heat than install a carbon adsorber. However, if the recovered solvent can be used as fuel, carbon adsorption compares favorably in operating cost with an incinerator. If the solvent can be recovered as usable solvent, use of carbon adsorption represents an economic advantage to the paper coater.

It is more difficult to estimate costs for low solvent coatings, because the cost will vary depending on the type of coating. Low organic solvent coatings will usually cost less in dollars per pound of coatings solids applied than will conventional organic solvent coatings with some type of add-on control device.

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6.0 AUTOMOBILE AND LIGHT DUTY TRUCK ASSEMBLY

6.1 Summary of Control Technology

Affected Facility[g]	Control Option	Percentage Reduction
Prime application and flashoff area*	Water-borne (electrodeposition)[a]	80[c]-93[d]
	>50 volume percent solids primer	0[c]-65[d]
	Incineration[b]	90+
	Carbon adsorption[b]	85+
Prime cure oven	Water-borne (electrodeposition)[a]	80[c]-93[d]
	>50 volume percent solids primer	0[c]-65[d]
	Incineration[b]	90+
Topcoat application and flashoff area*	Water-borne topcoat[a]	40[c,f]-92[e,f]
	>50 volume percent solids topcoat	0[c]-86[e]
	Incineration	90+
	Carbon adsorption	85+
Topcoat cure oven	Water-borne topcoat[a]	40[c,f]-92[e,f]
	>50 volume percent solids topcoat	0[c]-86[e]
	Incineration	90+

(a) These options reduce emissions from application, flashoff and cure. The percentage reduction given is the reduction from all of these sources.

(b) Applicable but not costed in this report since water-borne primer is likely the preferred method.

(c) Based on an original coating with 50 volume percent solids. (3.7 lbs/gal)

(d) Based on an original coating with 26 volume percent solids. Surfacer (guidecoat) is included. (5.5 lbs/gal)

(e) Based on an original coating with 12 volume percent solids. (6.5 lbs/gal)

(f) Based on a water-borne topcoat with 2.76 pounds of organic solvent per gallon of coating minus water (e.g., 25 volume percent solids, 15 volume percent organic solvent and 60 volume percent water).

(g) These control options are applicable to all assembly and subassembly lines in the plant including those for frames, small parts, wheels, and main body parts.

*The application area(s) is (are) the area(s) where the coating is applied by dip or spray. The flashoff area is the space between the application area and the oven.

6.2 General Discussion

For purposes of this study, "automobiles" includes all passenger cars or passenger car derivatives capable of seating 12 or fewer passengers. "Light duty trucks" includes any motor vehicles rated at 8500 pounds gross vehicle weight or less which are designed primarily for purposes of transporation of property or are derivatives of such vehicles. This is intended to include pick-ups, vans and window vans.

The automobile and light duty truck assembly industry receives parts from a variety of sources and produces finished vehicles ready for sale to vehicle dealers. Various models may be built on one line, but they usually are of the same general body style. A plant may have more than one line. This chapter is intended to apply to assembly plants only and not to customizers, body shops or other repainters.

Although faster production is possible, automobile and light truck assembly lines typically produce from 30 to 65 units per hour using two (or rarely three) worker shifts per day. Plants are usually shut down on holidays and for several weeks during the model changeover period. Most plants operate about 4000 hours per year,[1] depending on demand.

Locations of U.S. automobile and light duty truck assembly plants include: American Motors--Kenosha, WI, and Toledo, OH; Checker Motors--Kalamazoo, MI; Chrysler Corporation--Belvidere, IL, Hamtramck, MI, Detroit, MI (2), Newark, DE, and St. Louis, MO; Ford Motor Company--Atlanta, GA, Chicago, IL, Dearborn, MI, Kansas City, MO, Lorain, OH, Los Angeles, CA, Louisville, KY, Mahaw, NJ, Metuchen, NJ, Norfolk, VA, St. Louis, MO, San Jose, CA, Minneapolis - St. Paul, MN, Wayne, MI, and Wixom, MI; General Motors--Arlington, TX, Baltimore, MD, Detroit, MI, Doraville, GA, Fairfax, KS, Flint, MI, Framingham, MA, Fremont, CA, Janesville, WI, Lakewood, GA, Lansing, MI, Leeds, MO, Linden, NJ, Lordstown, OH, Norwood, OH, Pontiac, MI, St. Louis, MO, South Gate, CA, Tarrytown, NY, Van Nuys, CA, Willow Run, MI and Wilmington, DE; and International--Springfield, OH. A plant is under construction by Volkswagen in Pennsylvania. Volvo, who had planned a new plant in Virginia, recently announced their plant has been postponed "indefinitely".

Although no "typical" automobile or light truck assembly line exists, features common to all are shown in Figure 6-1. As the process begins, an automobile body emerges from the body shop and undergoes metal treatment (usually a phosphate wash cycle) to improve paint adhesion and corrosion resistance.[2,3] The first coat, a primer, is applied by dip and/or spray methods, then the unit is baked. The topcoat is then applied in one to three steps, usually with a bake step after each. The painted body then goes to the trim shop where assembly is completed.

Coatings which are damaged during the trim step are repainted in a repair spray booth. Because the automobile now contains heat sensitive materials such as plastics and rubbers, repair is generally limited to solvent-borne coating, which can be dried in low-temperature ovens. (Water-borne coatings usually require high curing temperatures.) Production volume in the repair area is intermittent, making add-on emission control devices less cost-effective than for the primary coating area. Emission controls, therefore are generally not practical for the repair spray booth and its oven. Considerable reductions in emissions can be accomplished by the use of a higher solids repair coating.

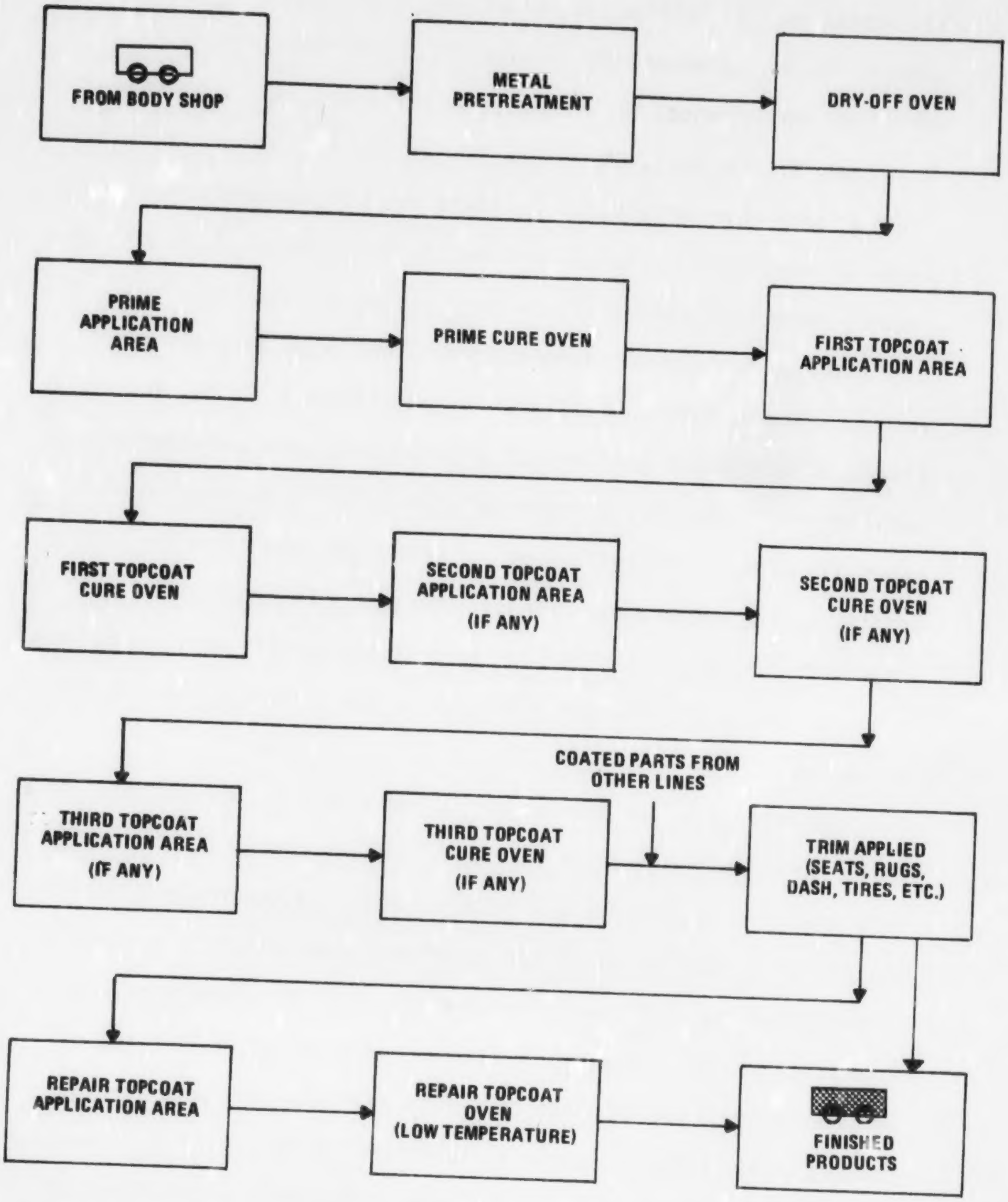

FROM BODY SHOP
METAL PRETREATMENT
DRY-OFF OVEN
PRIME APPLICATION AREA
PRIME CURE OVEN
FIRST TOPCOAT APPLICATION AREA
FIRST TOPCOAT CURE OVEN
SECOND TOPCOAT APPLICATION AREA (IF ANY)
SECOND TOPCOAT CURE OVEN (IF ANY)
THIRD TOPCOAT APPLICATION AREA (IF ANY)
THIRD TOPCOAT CURE OVEN (IF ANY)
COATED PARTS FROM OTHER LINES
TRIM APPLIED (SEATS, RUGS, DASH, TIRES, ETC.)
REPAIR TOPCOAT APPLICATION AREA
REPAIR TOPCOAT OVEN (LOW TEMPERATURE)
FINISHED PRODUCTS

Figure 6-1. General flow diagram for automotive and light truck assembly plants. Main bodies may be on separate lines from hoods and fenders.

Cost estimates and pollutant emissions presented in this chapter are based on coating main body parts including hoods and fenders. In some plants (particularly those building larger vehicles), hoods and fenders are coated separately and joined to the body after coating. The total cost of controlling emissions may be more if the coating is done on several lines instead of one line.[1]

Some automobiles and most trucks have a separate frame that is joined to the body after coating. Frames and small parts such as wheel rims may arrive at the assembly plant already coated or may be coated at the assembly plant. These sources of emissions are liable to the same control measures as those for the main body and this report applies.

Parts that are not visible from the exterior of the vehicle may be dipped in a viscous coating that can be either water-borne or solvent-borne. Headlight frames and other visible small parts may arrive at the assembly plant already coated, be coated after assembly to main body parts, or be coated on a separate line. As with the other vehicle components, the coating process for these parts is liable to the same control measures used for the main body.

Uncontrolled organic emissions from coating vehicles with organic solvent-borne surface coatings can range from less than 600 pounds per hour (lb/hr) to more than 4000 lb/hr for an assembly line. This wide range is caused by variations in the surface area coated for different vehicles, the number of vehicles coated per hour, and, most importantly, the solvent content of the coatings. There may be more than one assembly line at a plant.

Other sources of organic emissions from a vehicle assembly plant that are not included in this study include the application of adhesives and sound-proofing materials. These account for about 10 to 30 percent of total organic emissions from the plant.

6.2.1 Materials Used - Two types of coatings are used in this industry: lacquers and enamels. Lacquers are resin-pigment combinations dissolved in a high solvent-power solvent. Drying occurs by evaporation of the solvent and deposition of the resin and pigment, rather than by cross-linking.[4] Enamels are highly pigmented drying oils thinned with a low-solvent-power solvent. The coating is formed by polymerization.

The uses of coatings can be divided into primers and topcoats. Acrylic coatings may be either lacquers or enamels and are widely used for topcoats. Topcoats currently used contain from about 14 to 35 percent solids by volume. Primers are usually enamels and are complex polymers prepared from epoxy and drying oil acids. Primers are usually either solution epoxies (cross-linked with a urea or melamine) or electrodeposition primer resins.[2] A typical solids content of a solvent-borne primer enamel would be 26 volume percent for General Motors[4] and 30-35 volume percent for Ford.[19]

Since most manufacturers apply about a 3.0 to 3.5 mils thick coating, the mass of solvent emitted per unit surface area is proportional to the ratio of solvent to solid material in the coating. The relationship between pounds of solvent (assuming a solvent density of 6.6 lbs/gal) emitted per gallon of solids applied and the percentage of organic solvent present is shown in Figure 6-2. The relative positions of the various types of coatings emphasize the great differences in emissions between coatings of different solids content, e.g., between lacquers and enamels. Even though the positions of lacquers and enamels on this figure do not represent absolute numbers (since exact percent solids and solvent density can vary), the difference is striking. The amount of organic solvent contained per unit of solids (as used) factor is a convenient comparative tool because it is independent of vehicle size, line speed, and coating thickness.

6.2.2 Processes and Affected Facilities - Four types of facilities are affected: (1) prime application area(s), including flashoff area (evaporation area prior to the oven); (2) prime cure; (3) topcoat application area(s), including flashoff area but excluding repair application area; and (4) topcoat cure, excluding repair oven.

The prime coat serves the dual function of protecting the surface from corrosion and providing for good adhesion of the topcoat. A combination of manual and automatic spray methods, with or without the use of electrostatic techniques, is usually used to apply organic solvent-borne primer. Because workers are in the spray area, health regulations require solvent concentrations be kept low. At some plants, vehicle hoods and fenders may have their own prime spray booth and oven. In rare cases, primers may be applied in more than one step with each followed by curing.

Primers may also be applied by dipping techniques. The Chrysler Corporation, for example, uses water-borne dip primers for underbodies

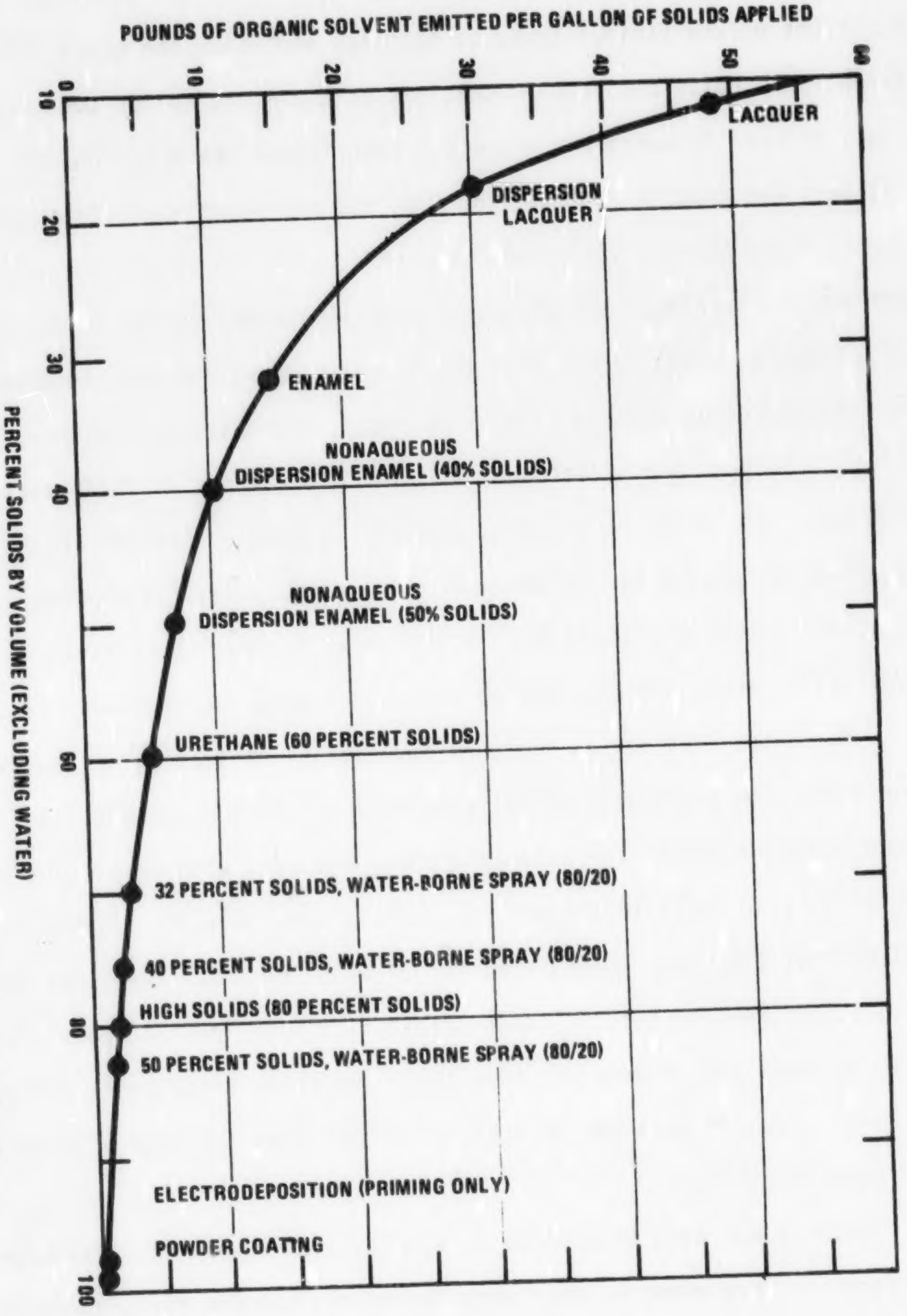


Figure 6-2. Percent of solids versus pounds of organic solvent emitted per gallon of solids applied. (Assumption: solvent density = 6.6 lb/gal).

at some of its plants. Because the dip-coated primer is not smooth, the coating must be sanded or else be used only on areas where appearance is not important.

Of most interest from a pollution control standpoint is total body priming by electrophoretic (electrodeposited) water-borne dip. In this system the object to be coated is immersed in a water-borne coating and an electric potential difference is induced between the vehicle and the coating bath. By correctly setting the electrical potential and the time in the bath, the coating thickness can be controlled as desired. Corrosion protection is excellent because coverage is more complete than can ever be obtained by spray priming alone. Additional primer may be sprayed on rough or sanded areas. This additional primer, called "surfacer" or "guidecoat", can be either water-borne or organic solvent-borne.

The paint in the electrophoretic bath consists of 5 to 15 volume percent solids, 80 to 90 volume percent water, and about 5 volume percent organic co-solvent. The coating solids displace solvent as they are deposited and solvent is squeezed out. As the vehicle component emerges from the bath, its coating is 90 volume percent solids, 9 volume percent water and 1 volume percent organic co-solvent. Excess coating is returned to the bath by washing with makeup and ultra-filtered water. Because of the extremely low solvent usage (about 7 lb/hr), the exhaust from this oven does not require further emission control unless it presents an odor problem. The electrophoretic dip process is used at over 40 percent of U.S. assembly plants and is very widely used in Europe.[1,5,6,7]

An option suitable for some plants is to spray a water-borne primer.

Organic solvent-borne primers are usually spray applied. When using organic solvent-borne spray, 85 to 90 percent of the solvent evaporates in the booth and flashoff area; the remaining 10 to 15 percent evaporates in the oven.

Water-borne coatings contain relatively small quantities of organic solvents, principally to improve leveling and gloss. They are less volatile organics than those from organic solvent-borne coatings and consequently a lower proportion evaporates in the booth(s) and flashoff area(s). For water-borne topcoats, the calculations here assume that 50 percent evaporates in the spray booth(s) and flashoff area(s) and 50 percent in the cure area(s). Note that maximum humidity limitations (for proper curing), the necessity of an adequate air flow at oven entrance, and avoidance of explosive mixtures, all affect required oven exhaust volume for water-borne coatings.

A relatively new system of coatings called "autophoretic" has been used for frames and parts. This system has been proven for these applications but has not been applied to primers or topcoats.[8,9,10] It is unknown at this time if the system can be used for parts of the vehicle that are normally visible.

6.3 Special Considerations

With respect to the coating process, the automobile and light truck assembly industry has characteristics that make it unique. The companies involved are large and possess a great deal of expertise in coatings (unlike some other companies that coat their products), the entire process is under their control, and they are free to change coatings, within the limits of their equipment, (unlike toll coaters that often have no choice in the coatings they use). These tend to facilitate control, especially the use of low-solvent coatings. The process can, and usually does, run at a relatively high percentage of capacity and at a constant rate-which tends to make control more cost-effective. The industry produces a product that is expensive to inventory, must be responsive to customer whim, and is available with a large number of options and colors. These make frequent color change a necessity and hence the use of powder coating difficult. The industry has strong competition from foreign imports, and produces a product that is exposed to a wide range of climates and is judged critically by its appearance. These considerations make the use of unproven coatings more difficult.

Special considerations drastically affect the cost of control. To obtain acceptable appearance and coverage on a complex shape such as a car or truck, manufacturers have found it necessary to apply topcoats by a combination of manual and automatic spray. Multiple applications are necessary to achieve the necessary thickness, and sufficient time must be allowed between applications for adequate drying. Sufficient space also must be provided between vehicles on a moving assembly line to allow the operator to complete his task. All of these factors cause spray booths to be as much as several hundred feet long. Because the booth is occupied, OSHA requires a minimum air velocity away from the workers to protect them. This requirement is normally met by maintaining a minimum air movement from top to bottom of the booth. This air flow, in conjunction with the long spray booths characteristic of the industry, results in exhaust volumes of hundreds of thousands of cubic feet per minute. The concentrations of organic vapors range from 50 to 200 ppm (equivalent to less than 2 percent of the lower explosive limit, i.e., the LEL) at temperatures of 60°F to 90°F. This combination of high volume and low concentration makes add-on devices very expensive for spray booths.

Ovens are not restricted to the same low organic concentrations since they are not occupied. Their allowable concentrations are governed by three factors: explosivity limits (usually to less than 25 percent of LEL), the necessity to maintain adequate air inflow at openings to prevent escape of oven gas, and the necessity to prevent condensation of high boiling compounds on the inner surfaces of the oven. Although improved oven entrance design can help in the future, the problem of adequate inlet flow presently limits motor vehicle assembly plant ovens to a maximum of about 10 percent of the LEL.[11] The condensation problem may begin to occur at higher concentrations.[7] With many older ovens, modifications may be necessary to raise the concentrations even to 10 percent of the LEL.

Besides minimizing the size and fuel requirements of the control equipment, operating ovens at the higher concentrations has the additional advantage of minimizing the fuel requirements of the oven itself by decreasing the quantity of makeup air to be heated. The higher temperature and the higher concentration (with correspondingly lower exhaust flow rates) makes incineration much less costly for an oven than for a spray booth.

Some special considerations make powder coating difficult. These are the necessity to change colors often and the desirability of "metallic" coatings. It would be desirable both from a manufacturing and air pollution standpoint to switch colors as seldom as possible. Manufacfacturers would like to schedule many vehicles of one color through the line in sequence for convenience and to save the paint that must be purged from spray nozzles each time a color is changed. Unfortunately, vehicles are built with a large number of available options, of which color is only one. Air conditioners, power brakes, power steering, etc., are each installed on a given percentage of the production volume. Each of these subassembly operations has a production capacity that may be less than the line speed and each has a finite storage capacity. Vehicles are largely built to dealer or customer orders which must be filled within a limited time. The scheduling of vehicles on the assembly line is, therefore, constrained by many factors and color change is often necessary between each vehicle. The capability must exist to change colors quickly in the booth, or else separate application areas must be available for each color. Because an assembly plant usually applies in excess of 15 colors, the latter choice is economically prohibitive.

Spraying powders of different color in one booth also has problems. In the conventional spray system, each color is delivered through a separate hose and the operator manually switches his spray nozzle among the hoses. The former color is first flushed out of the nozzle with the new color and then coating with a new color begins. Inertial deposition is the primary coating mechanism although electrostatic attraction may assist. Once the coating material strikes the surface it agglomerates and is not then susceptible to reentrainment. High air velocities are maintained in the booth to meet health requirements and to prevent overspray from one vehicle to another. In contrast to this, powder does not coalesce: the sole force holding the powder is electrostatic attraction. Furthermore, the small particle size makes it impractical to use the high sweep velocities required for worker safety (because of entrainment). Exhaust velocities must be kept low. These low exhaust velocities make it necessary to use largely automated coating systems and require face masks where workers are essential. The low velocities can result in carryover. Any carryover of coating in a powder system shows up as discrete specks on a differently colored product since there is no opportunity for dilution of carryover paint specks as in liquid-borne coatings.

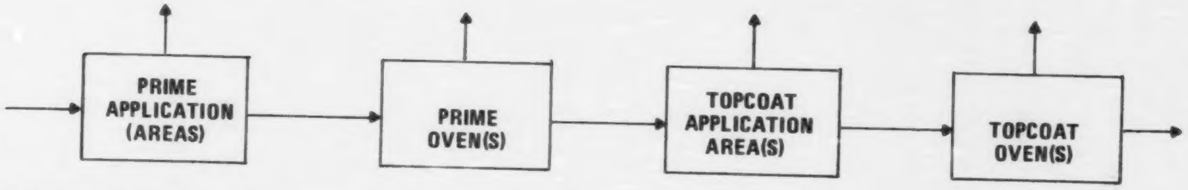
Metallic coatings, much in demand for automobiles, obtain their name from platelets of aluminum added to give a reflective appearance. In a powder system, the platelets cannot move after application and are thus set in a random order. The appearance is less aesthetically pleasing than that achieved with liquid-borne coatings where the platelets orient parallel to the surface.[4]

To date these problems have been an obstacle to the adoption of powder coatings as topcoats in this industry.

6.4 Available Control Technology

For ease of comparing control technology, a flowchart of a typical plant is shown in Figure 6-3. As outlined at the beginning of this section, certain technologies are limited to certain affected facilities and some will reduce emissions from more than one affected facility

COATINGS, SOLIDS, b.v. SOLVENTS, AND TYPE	PRIME APPLICATION		PRIME OVEN		TOPCOAT APPLICATION		TOPCOAT OVEN	
	SOLVENT EXHAUST RATE, lb/hr	FLOW RATE, x 10^3 scfm	SOLVENT EXHAUST RATE, lb/hr	FLOW RATE, x 10^3 scfm	SOLVENT EXHAUST RATE, lb/hr	FLOW RATE, x 10^3 scfm	SOLVENT EXHAUST RATE, lb/hr	FLOW RATE, x 10^3 scfm
12% SOLUTION LACQUER					2490	1815	438	25.0
18% DISPERSION LACQUER					1546	1129	212	15.5
32% ENAMEL	360	262	64	4.5	720	525	127	6.0
50% ENAMEL	170	123	30	1.6	340	248	60	3.4
WATER-BORNE	NEGLIGIBLE	SMALL	40	1.6	85	525	85	3.4



ASSUMPTIONS: SOLVENT CORRESPONDS TO 50-50 mole percent HEXANE-BENZENE; 85 percent OF EMISSIONS ARE IN APPLICATION AREA(S) FOR SOLVENT-BORNE COATINGS; 50 percent OF EMISSIONS ARE IN APPLICATION AREA(S) FOR WATER-BORNE TOPCOAT; 30 gal/hr OF SOLIDS ARE APPLIED FOR PRIME COAT; 60 gal/hr OF SOLIDS ARE APPLIED FOR TOPCOAT; APPLICATION AREA EXHAUST AT 100 ppm WAS 0.0228 lb/10^3 scf; OVEN EXHAUST AT 10 percent OF LEL WAS 0.296 lb/10^3 scf; ORGANIC SOLVENT DENSITY WAS 6.665 lb/gal. FOR WATER-BORNE, percent OF LEL WAS LOWER.

Figure 6.3 Typical plant for assembling intermediate-sized automobiles and light-trucks at rate of 60 per hour. (For different vehicles, the values would correspond to different production rates.)

(e.g., transition to water-borne coatings will result in reduced emissions from both the application and curing areas). Some technologies can be combined (e.g., incineration will further decrease emissions even after a plant changes to coatings with higher solids content).

Caution must be used in applying the cost estimates below to specific plants, since retrofitting costs can vary greatly depending on the specific situation. In some cases the assumptions used herein are for an almost ideal case; any deviation will increase the cost. One should carefully analyze each situation to determine if the assumptions are valid or the deviations essential (for example the cost of control for a given amount of organic material is roughly inversely proportional to concentration but exhaust gases in most ovens are far more dilute than necessary). The paint usage assumptions can also vary considerably between plants.[12] In all cases, the assumptions (and where possible the effects on costs of different assumptions) are listed, either in this Section or in Section 4 of Volume I.

The control options described have varying levels of current use in assembly plants. Water-borne primers are currently used in almost half of the plants. Water-borne topcoats are being used at two plants and their use is planned at a third. Incineration of oven exhaust has been used at a number of plants. Topcoats with greater than 50 volume percent solids have not yet been used but this level is being approached. One company plans to use topcoats with greater than 70 percent solids before 1981.[25] Incineration or adsorption of spray booth exhaust, although technically feasible, has not been used at any plant. Carbon adsorption of spray booth exhaust would require pilot studies because of known potential problems. Thus the timetable and cost of compliance are more uncertain using carbon adsorption than for other methods.

Finally, it should be noted that inclusion of a discussion of a technology in this report indicates it is technically feasible, that is that no invention is required for its implementation. No judgement is made as to its reasonability or advisibility for a given situation, from a standpoint of either cost or energy.

6.4.1 Option 1 - Electrodeposition of Water-Borne Primer - This option assumes electrophoretic (electrodeposited or electrocoated) application of primer to the vehicle. Spraying of water-borne primers is possible, but it does not achieve the same coverage or lend itself to automation as well as the electrophoretic method does. Water-borne spray priming is used at some plants and it is a viable option for many plants. It is important to evaluate the ratio of organic solvent to solids for spray primers and the losses due to overspraying to determine the effectiveness of this option.

Achievable Reduction - The amount of organic solvent in an electrophoretic coating is less than 0.15 lbs per gallon (minus water). However, solvent emitted from evaporation in the tank and from the "surfacer" used after the dip increases the overall total to about 1.9 lbs per gallon (minus water). The percentage reduction achieved by a change to electrophoretic coatings depends on the original system. For example, if the change is from a 32 volume percent solids primer (about 5.3 lbs of organic solvent per gallon of coating) to electrophoresis (about 1.9 lbs of organic solvent per gallon of coating), the reduction is 80 percent.

Technical Analysis - A description of electrophoretic priming (electrodeposition or electrocoating) is provided in Section 3.3.1 of Volume I. As discussed earlier, electrophoretic priming requires better precleaning of the metal than does an organic solvent-borne primer and it requires a final rinsing with deionized water before priming.

With an organic solvent-borne system, the assembly line can be stopped overnight, on weekends, or during shift changes and breakdowns. This is not possible with electrophoretic primer or with other waterborne systems because of the potential for rusting and dirt pick-up (due to the longer time it stays wet). Thus, vehicles covered with waterborne coatings cannot be left for long periods of time before being baked and the assembly lines must have the capability of carrying coated vehicles through the oven after assembly line shutdowns. Accommodations must also be made for storage of these vehicles or parts until the line starts up again. This necessity for surge storage areas and independent conveyor chains for each of the spray booths results in additional conveyor controls and costs.

The major limitation of electrophoretic dip coating is that it can be used only directly over metal or other conductive surfaces. It is limited to one-coat applications or primer finishes, and there is a practical maximum thickness that can be achieved.[2] A bath can only contain one color so a separate bath would be necessary for each color. None of these problems adversely affects the use of electrophoretic dip for primer, but they do make it unusable for motor vehicle topcoats. Electrophoretic dip coating is a fully demonstrated technology.[13]

A consideration for any control option is natural gas usage. In electrophoretic dip priming, gas is used in the ovens. Although higher temperature must be maintained for a longer time period than when curing conventional primers, organic solvent emissions are far less. Thus, required air flow may be reduced (this is limited by the ventilation necessary to keep oven gases from escaping and to remove reaction products from the oven).[4] Unlike organic solvent-borne primer, no dry-off of the body after cleansing is required prior to the electrophoretic coating, therefore it eliminates fuel usage for this purpose.

Electrical requirements increase by about 1400 kilowatts by a switch to electrophoretic coatings. Electrical requirments for applying the coating are about 1000 amps at 400 volts (400 kilowatts). Ford reports that their plants use 1500 amps at 200 volts (300 kilowatts).[1] Cooling requirements for the bath are about 150 tons of refrigeration, equivalent to about 1300 kilowatts. Some additional power is also required for the agitation and ultrafiltration steps. Note that up to a 300 kilowatt credit in power usage can be taken because most of the 120,000 to 260,000 scfm exhaust from replaced spray booths is no longer required. (Some spray booths may still be needed for surfacer.) Depending on climate, this air would have to be heated in the winter, usually by natural gas, steam or propane. Finally, there is no increase in pumping requirements since the circulation in the bath that is necessary in electrophoretic systems for mixing and water circulation is offset by elimination of the water which would be required in the spray booths for collecting particulate.

In summary, since an assembly line applying organic solvent-borne primers uses about 12,000 KW of electricity, the 1400 kilowatt increase caused by electrophoresis represents a 12 percent increase.

Cost of Control Option - The principal disadvantage of electrophoretic dip priming is its high capital cost. Maintenance costs are equal to or less than those for conventional spray systems and operating labor is reduced. More coating is applied per vehicle than when spray is used because coverage is better but total paint usage is about equal to spray coating because there is almost no waste.

The installed cost of an electrophoretic system for a typical vehicle assembly plant would be about $8 million. Costs can, of course, vary considerably depending on what building alteration and relocation of existing equipment is necessary. Table 6-1 gives increased operating costs for electrophoretic primer, based on electricity at $0.03/KWhr, interest and depreciation at 12 percent of capital costs, and operation for 4000 hours per year.

Effects and Limitations - Electrophoretic dip coatings contain amines that are driven off during the curing step. Some plants have found it necessary to incinerate the oven exhaust gas to eliminate the visible emission and malodors associated with these amines. No other adverse environmental effects appear to result from a change to electrophoretic dip coatings, and no apparent safety problems exist, assuming normal industrial procedures are followed. The energy impact was discussed earlier in this section.

TABLE 6-1. INCREASED ANNUAL OPERATING COST FOR ELECTROPHORETIC DIP PRIMERS COMPARED TO SOLVENT-BORNE PRIMER

Utilities:		
Electricity	\$.03/kWhr x 4000 hrs/yr x 1400KW	168,000
Direct labor: Savings of	8hrs/shift x 500 shift/yr 3 workers/ shift \$15/hr	-180,000[a]
Interest and depreciation	12 percent x (\$1,000,000 to 8,000,000)[b,c]	120,000 to 960,000
Total increased operating cost	---	108,000 to 948,000 \$/yr

[a] There is a net credit for labor cost for electrophoretic dip coating. The calculation is for the difference between one operator versus four in a conventional spray booth applying organic solvent-borne primer.

[b] Assuming 20 year life, 10 percent interest.

[c] The range of values is for different ages of the existing prime line. The lower value represents the increased total installed cost of an electrophoretic dip line over an organic solvent-borne prime line for a plant with an old prime line ready for replacement. The higher value represents the total installed cost for a plant with a new solvent-borne prime line.

6.4.2 Option 2 - Lower Solvent Primer and Topcoat - This option is the use of lower solvent (higher solids) organic solvent-borne systems (not to be confused with "high-solids" coatings discussed in Volume I, Section 3.3.2). At many of its plants, General Motors uses lacquers for the topcoat. Lacquers have very low solids content (∿14 volume percent). Ford, American and Chrysler use topcoat enamels with 22 to 35 percent solids by volume (∿33 to 45 weight percent). Volkswagen expects to use topcoats with ∿70 volume percent solids (80 weight percent) by 1981.[25] Current solvent-borne prime coats vary from 26 volume percent[4] to 37 volume percent (sealer at new Volkswagen plant). European and Japanese manufacturers use enamels almost exclusively.[7]

This option examines the general effect that raising the solids content of coatings has on emissions. The choice of 50 volume percent solids as a base is intended as an example only since any increase in solids content can dramatically reduce emissions, as shown Figure 6-2. An obvious improvement would be a change from a low solids lacquer system to a higher solid enamel system.

Any regulation calling for a minimum solids content should be based on an average over at least an hour since the solids of different colors and coatings can vary within a plant. Distinction between weight percent and volume percent solids is also necessary.

Achievable Reduction - The achievable reduction again depends on both the old coating and its replacement. For example, the 50 volume percent coating achieves an 86 percent reduction if it replaces a lacquer with 12 volume percent solids, but only a 53 percent reduction if it replaces an enamel with 32 volume percent solids. Obviously, even further reductions can be achieved if an add-on control device is also installed.

Technical Analysis - There are no significant changes in operating requirements necessary to switch to lower solvent coatings. Nozzles would have to be slightly modified as would procedures for application and curing, but generally, the same equipment would be used. Oven exhaust volumes could be reduced considerably, as could the number of spray booths, if lacquers were replaced with enamels.

There are no unresolved technical problems associated with this option. At present only General Motors uses lacquer for vehicles, but even they apply enamel to many of their light trucks and some of their automobiles. General Motors recently converted their Kansas City assembly plant from applying lacquers to enamels on a trial basis.[4]

Cost of Control Option - Typical capital costs for this option are difficult to assess because they depend completely on the specific plant situation. We estimate a change from lacquer to enamel would require a capital cost (including engineering) of $1,000,000. (General Motors claims that it would be higher.) Based on a rule of thumb 12 percent of capital investment, annualized operating costs could be as high as $120,000 per year although this would be affected by the lower manpower required to apply enamels and the increased manpower which would be needed to repair damaged coatings.[4,14]

Effects and Limitations - The chief impact of this option would be on General Motors (GM) Corporation, the only company still predominantly using the lacquer system.

The energy required to cure enamels should be less than for lacquers because of lower exhaust flow rates (since fewer coats are needed, fewer booths are used and less solvent is evaporated). This potential energy savings is partially offset by the higher temperature required for curing enamels.

6.4.3 Option 3 - Carbon Adsorption for Primer and Topcoat Spray Booths - As discussed in Section 6.2 of this volume, 85 to 90 percent of the solvent emissions from organic solvent-borne coatings occur in the spray booth and flashoff area and only about 10 to 15 percent in the ovens. This option considers installation of carbon adsorbers to control organic emissions from the spray booths and flashoff areas where it is assumed 85 percent of the emissions occur.

Achievable Reduction - Reductions of greater than 85 percent can be achieved using carbon adsorption to control emissions from primer and topcoat spray booths.[15,16,17]

Technical Analysis - Spraying processes for topcoats and primers are subject to the same health-related constraints on concentration because an operator is required in the booth. Thus the organic concentrations in the exhaust typically average about 100 ppm and can be lower. Some areas, such as the booth for two-tone coating jobs, have significantly lower average concentrations.

There are problems in the application of carbon adsorption for automotive and light duty truck spray booths. These problems, which arise from the presence of particulate matter and water miscible organics in the inlet stream and from high humidity, are solvable. General Motors has acknowledged that activated carbon can be effectively used on spray booths and ovens to reduce solvent emissions by 90-95 percent if the carbon adsorption system is properly engineered and regularly maintained.[16,17]

For instance, although excessive particulate matter can reduce carbon life, spray booths generally already use some type of particulate control. In smaller booths this may be a panel filter, although in the more typical larger booths, 95 percent efficient water scrubbers (water-wash booths) are used to give a low particulate concentration level.[4] The remaining 5 percent could still have a significant effect on an adsorber but additional particulate removal can be used if necessary. Such particulate removal has not been included in cost estimates. A humidity problem, if any, can be solved by reheat of the gases. About a 10°F reheat may be necessary to reduce the relative humidity below 80 percent. Solvents that are deleterious to carbon can be avoided. Spray booth temperatures are too low to degrade common solvents or vaporize or break down any of the resins into compounds that can cause problems.

As with any add-on control device, the capital cost is largely dependent on the flow rate. Generally anything that decreases flow rates of exhaust will decrease capital and fixed operating cost. Possible methods of reducing flow rates include reduction of velocities past the workers (yet remaining in compliance with health requirements) and recirculation of cleaned exhaust air from manned spray areas to unmanned areas using automatic spray.[14,18] Improved automatic spray machines under development will enable the use of a wider variety of coatings and also decreased ventilation.[4] Another avenue that might be profitably explored is to protect workers with breathing masks supplied with an exterior source of clean air. This would permit reduced exhaust flow rates limited only by the necessity of providing adequate ventilation to avoid cross-contamination of vehicles on the line and by health regulations.[14] An attractive possibility, especially for users of lacquers, is to switch to higher solids material to reduce flow rates before applying carbon adsorption; the lower the flow rate, the lower the cost.

Questions that have been raised in comments to drafts of this report as to the validity of the assumptions on which we predicate carbon adsorption can be satisfactorily answered. There is, of course, no one "typical solvent mixture" for motor vehicle coatings. The important factor in assuming a solvent for cost estimation purposes is that it be representative of the actual solvents used (to the greatest degree possible) in the characteristics important to the control technology being evaluated. The mixture of hexane and benzene meets these criteria for carbon adsorption. This mixture was chosen because it represents the two largest classes of solvents (aliphatic and aromatic hydrocarbons) used, because the molar volumes of these compounds are representative of most solvent blends (see Section 3.2.1 of Volume I of this series for the importance of this), and because cost data were available. The question of the miscibility of the solvents will be covered in the next section.

Although carbon adsorption is technically feasible, (i.e., no new inventions are needed for its implementation), no full-scale installations are presently in operation on automobile or truck assembly plant paint spray booths. As noted earlier, pilot studies would be necessary for use of this technology.

Cost of Control Option - These costs were estimated assuming adsorber modules, each capable of handling 50,000 cubic feet per minute. Total costs for a system would be a multiple of the cost for one. Special designs for high volume low concentration flows are possible to lessen capital costs, but were not investigated for this study.

Three cases are costed in Table 6-2. (Note that although these estimates include installation, actual costs could be higher for difficult retrofit situations. Ford estimates that capital costs would be about 80 percent higher.[19]) The first is with solvent recovery and no credit for solvent. The second case, which is for solvent recovery with credit as fuel only, is probably the most reasonable assumption for assembly plants. The third case is credit for the solvent at its solvent value. Assembly plants generally use multi-component solvents and reuse would be difficult.[4]

Impacts and Limitations - Due to the pressure drop associated with gas flow through a carbon adsorber and the large volumes of air through spray booths, the electrical requirements for handling air are large. Steam consumption for desorption is also large because of the large amounts of low concentration gas. (See Section 3.2.1 of Volume I of this series for details.) Some solvent used in assembly plants are sufficiently water miscible to pose a water pollution problem if regeneration steam is condensed and discharged untreated.[4,14] Many of these compounds (e.g., alcohols, esters and ketones) are primarily in the formulation to comply with regulations based on photochemical reactivity such as contained in the former Los Angeles APCD Rule 66 (now Southern California Air Pollution Control District Rule 442). With effective add-on controls, less expensive water-immiscible solvents could be employed. Carbon adsorption of these "non-exempt" solvent blends

TABLE 6-2. COST ESTIMATES FOR AUTOMOBILE AND LIGHT TRUCK ASSEMBLY PLANTS WITH CARBON ADSORPTION FOR TOPCOAT SPRAY BOOTHS AND FLASHOFF AREAS[a]

	CASE 1	CASE 2	CASE 3
Cost	No credit for solvent	Fuel value for solvent	Solvent at solvent prices[b]
Capital cost per 1000 ft^3/min	10,820	10,820	10,820
Total capital cost, \$ x 10^6	2.7[c] - 19.6[d]	2.7[c] - 19.6[d]	2.7[c] - 19.6[d]
Annualized operating cost per 1000 scfm, \$	4,162	4,003	3,643
Total annualized operating cost, \$ x 10^6	1.0[c] - 7.3[d]	0.99[c] - 7.26[d]	0.90[c] - 6.61[d]
Steam use, lb/hr x 10^3	7[c]-55[d]	7[c]-55[d]	7[c]-55[d]
Cost per ton of organic removed, \$	1,153	1,110	1,005

[a] Based on 100 ppm of hexane-benzene - 90 percent removal and 5840 hrs per year operation. Correction factors for different operating hours assumptions and a list of other assumptions can be found in Chapter 4 of Volume I. Note that costs for condensate stripping (if necessary) are not included.

[b] It is very unlikely that recovered organics could be reused as solvents.

[c] Based on 50 percent solids topcoat (248,000 scfm).

[d] Based on 12 percent solids topcoat (1,815,000 scfm).

(e.g., toluene and xylene) would be less difficult[14] although some treatment of the condensate might still be necessary. In cases where such a problem is unavoidable, the uncondensed steam (or hot air if hot air regenerated) and solvent can be incinerated together[15,16,20,21] or the condensate can be stripped and the miscible solvent disposed of properly. The size, fuel usage and the cost of this incinerator is many times less than if incineration were used alone.[21] There will, of course, be extra costs associated with these solutions. These costs are, however, difficult to quantify since they vary with the solvents used.

An important factor which must be considered before selecting carbon adsorption as a means of control is space. The exhaust from assembly plant topcoat spray booths and flashoff areas may need as many as 6 to 37 dual-bed carbon adsorption units in parallel operation. The floor area required by the adsorbers would be comparable to that occupied by the spray booths.

6.4.4 Option 4 - Incineration for Spray Booths

Achievable Reductions - Reductions in volatile emissions of 95 percent are achievable with incineration.

Technical Analysis - The basic requirement for noncatalytic incineration is to maintain sufficient temperature to combust the gases. For the cost estimates presented here, an exit temperature of 1400°F has been assumed. Depending on the solvents used, however, the operator may be able to lower this somewhat and still achieve sufficient oxidation of the organics.

Important operating requirements for catalytic incineration are the necessity to preheat and periodically clean or replace the catalyst. Monitoring or periodic testing of the exhaust gases is necessary to assure that combustion is complete.

Although there are no major technical problems associated with incinerating the exhaust from spray booths and flashoff areas, the high flow rates and very low organic vapor concentrations will require huge amounts of fuel. Moreover, the opportunity for more than primary energy recovery is limited due to inadequate outlet for the large amount of energy involved.

As with carbon adsorption, anything that lowers flow rates will lower capital costs. With incineration, lower flow will lessen the number of modules and the auxiliary fuel requirement. Incinerators have not been used to control spray booths of any kind but this technology has been used in processes with similar exhaust gas characteristics (e.g., for odors).

Cost of Control Option - Incineration was only considered for topcoat related streams since the advantages of electrophoretic dip coatings are such that this would likely be the preferred control method of reducing emissions from application of the prime coat.

The following three options were considered in estimating the cost of control.

1. Option one is use of incineration without heat recovery.

2. Option two is use of incineration with primary heat recovery, that is preheating of exhaust gases prior to incineration. The efficiency of heat recovery is 35 percent.

3. Option three is the use of a noncatalytic incinerator with 85 percent efficient primary heat recovery. This option was costed based on captial costs and fuel and electricity rates given in Reference 22. Labor cost were assumed to be the same as Option 2 and fuel costs were reduced. This option is being used on a coil coating line in Wisconsin.[23] Heat recovery efficiencies of up to 90 percent are available.

Cost estimates for these three options are summarized in Table 6-3. Secondary heat recovery was not costed as there is no apparent use for this energy.

Effects and Limitations - Small quantities of oxides of nitrogen will normally be formed during incineration (from atmospheric N_2). If there are nitrogen or sulfur-containing compounds present in the waste gas, higher levels of their oxides may be formed. Halogenated compounds will form acids upon combustion. The nitrogen oxides are formed primarily at high temperatures such as found in a burner flame and are thus minimized with high degrees of heat recovery. Thus, the heat recovery mandated by cost and energy considerations should minimize nitrogen oxide emissions.

The chief adverse effect of incinerating spray booth exhaust is high energy consumption. This can be reduced through the use of: coatings with lower solvent content, catalysts, and primary and secondary heat recovery. Before requiring incineration for spray booths one should contact local fire protection agencies for their approval.[4]

6.4.5 Option 5 - Incineration for Primer and Topcoat Ovens

Achievable Reductions - Reductions in volatile organic emissions of 95 percent are achievable using catalytic or noncatalytic incineration on oven exhausts.

TABLE 6-3. COST ESTIMATES FOR INCINERATION OF EXHAUST FROM AUTOMOBILE AND LIGHT DUTY TRUCK ASSEMBLY TOPCOAT SPRAY BOOTHS[22,24]

Costs	No heat recovery Option 1		38 percent efficient Primary heat recovery Option 2		85 percent efficient Primary heat recovery Option 3
	Catalytic	Noncatalytic	Catalytic	Noncatalytic	Noncatalytic
Capital cost per 1000 scfm, $	6,814	4,985	8,050	6,435	8,575
Total capital cost, $ x 10^6	1.6[a]-11.9[b]	1.3[a]-9.4[b]	2.0[a]-14.5[b]	1.5[a]-11.0[b]	2.1[a]-15.5[b]
Annualized operating cost per 1000 scfm, $	8,674	16,447	7,306	11,578	1,598
Total operating cost, $ x 10^6	2.1[a]-15.3[b]	4.1[a]-29.8[b]	1.8[a]-12.8[b]	2.9[a]-21.3[b]	0.4[a]-2.6[b]
Fuel, Btu/hr x 10^6	182[a]-1332[b]	494[a]-3612[b]	118[a,b]-862[b,c]	314[a,c]-2300[b,c]	53[a]-384[b]
Electrical requirements, kW	447[a]-3262[b]	349[a]-2553[b]	723[a]-5280[b]	719[a]-5250[b]	645[a]-4715[b]
Cost per ton of organics removed, $	2,110	4,120	1,820	2,910	402

[a] Based on 50 volume percent solids, 248,000 scfm from topcoat booth(s).

[b] Based on 12 volume percent solids (lacquer), 1,815,000 scfm from topcoat booth(s).

[c] Net energy usage considering recovered energy.

[d] Based on 95 percent removal efficiency.

Technical Analysis - There are no serious technical problems with the use of incineration for oven exhaust and incineration has been used on automobile and light truck assembly plant ovens.

Cost of Control Option - The control devices for the topcoat and the primer ovens would most likely be separate. Primer ovens have exhaust rates ranging from 1600 scfm to 4500 and are assumed to operate at 10 percent of the LEL. Topcoat ovens have exhaust rates ranging from 3400 scfm to 25,000 scfm, and are also assumed to operate at 10 percent of the LEL.

Table 6-4 shows estimated costs for primer and topcoat ovens operating at 10 percent of the LEL. Table 6-5 shows the cost for 15 percent of the LEL. Note that the exhaust volumes are 33 percent lower for 15 percent of the LEL for the same solvent volume. The 15 percent of the LEL case is included to show the benefits of minimizing dilution. It is important to note that most existing ovens are operated at less than 10 percent of the LEL. No cost was assigned to the modifications necessary to reduce air flow to achieve this concentration, however. The modifications would vary considerably and it is difficult to estimate a "typical" cost. Since reduction of exhaust flow has a dramatic effect on consumption of increasingly scarce and expensive natural gas, this modification would seem to be mandated, even without pollution control considerations.

Effects and Limitations - As illustrated by Tables 6-4 and 6-5, the fuel consumed by incinerators for ovens need not be excessive if the ovens operate above 10 percent of the LEL. If ovens were operated at

TABLE 6-4. COST ESTIMATES FOR INCINERATION OF EXHAUST OF PRIME AND TOPCOAT OVENS FOR AN AUTOMOBILE LIGHT TRUCK ASSEMBLY PLANT[24] (AT 10 PERCENT OF THE LOWER EXPLOSIVE LIMIT)

Flow rate[a] and option	Capital cost for prime oven, $	Annual operating cost for prime oven, $/yr[e]	Total capital cost, $[e]	Annual Total operating cost, $/yr[e]	Net energy used, x 10^6 Btu/hr[e]	Electrical requirements kWe	Cost per ton of organic removed[d], $/ton
Lower							
Option 1							
Catalytic	52,800[b]	23,000	136,000	60,700	1.5	13	242
Noncatalytic	31,400[b]	35,900	132,000	99,200	6.6	12	397
Option 2							
Catalytic	79,400[b]	28,200	204,000	73,000	0.8	21	294
Noncatalytic	69,200[b]	31,000	157,000	83,700	3.9	18	335
Option 3							
Catalytic	71,000[b]	23,900	182,000	61,354	Negligible	24	245
Noncatalytic	71,900[b]	27,100	185,000	71,003	Negligible	24	284
Higher							
Option 1							
Catalytic	98,000[b]	46,200	298,000	237,000	8.8	110	154
Noncatalytic	95,000[b]	81,100	238,000	424,000	39.0	83	277
Option 2							
Catalytic	48,000[b]	54,800	396,000	212,000	4.6	145	138
Noncatalytic	18,000[b]	67,100	298,000	311,000	23.5	127	203
Option 3							
Catalytic	32,000[b]	45,400	422,000	182,000	Negligible	166	118
Noncatalytic	134,000[b]	53,400	349,000	209,000	10.8	166	137

[a] Lower flow rate (50% solids enamel): 1600 scfm for prime oven; 3400 scfm for topcoat oven. Higher flow rate (32% solids primer and 12% solids lacquer topcoat): 4500 scfm for prime oven; 25,000 scfm for topcoat oven.

[b] Calculated from data for 5000 scfm using six-tenths rule.

[c] Recommended fuel rate at 22.6 percent LEL - credit for recovered energy (if any).

[d] Based on 95 percent removal.

[e] Prime and Topcoat

TABLE 6-5. COST ESTIMATES FOR INCINERATION OF EXHAUST OF PRIME AND TOPCOAT OVENS FOR AN AUTOMOBILE OR LIGHT TRUCK ASSEMBLY PLANT (AT 15 PERCENT LOWER EXPLOSIVE LIMIT)[24]

Flow rate[a] and option	Capital cost for prime oven, $[b]	Total capital cost, $ [e]	Annual total operating cost, $/yr [e]	Net energy used, x10^6 Btu/hr [e]	Electrical requirements, kW [e]	Cost per ton of organics removed, $/ton [c,e]
Lower						
Option 1 (No heat recovery)						
Catalytic	42,100	106,000	48,600	1.2	10.6	195
Noncatalytic	41,000	106,600	58,800	2.8	8.2	236
Option 2 (Primary heat recovery)						
Catalytic	49,000	123,500	42,500	.2	13.3	171
Noncatalytic	48,800	122,800	48,500	1.13	12.2	195
Option 3 (Primary and secondary Heat recovery)						
Catalytic	56,700	142,700	42,500	- .67[d]	16.0	171
Noncatalytic	57,400	144,500	44,000	- .13[d]	16.2	177
Higher						
Option 1 (No heat recovery)						
Catalytic	122,000	281,000	197,400	9.0	80	108
Noncatalytic	112,000	239,000	254,000	21.5	62	139
Option 2 (Primary heat recovery)						
Catalytic	146,000	340,000	147,000	1.5	100	81
Noncatalytic	126,000	281,000	163,000	8.5	92	89
Option 3 (Primary and secondary heat recovery)						
Catalytic	170,000	400,000	105,000	-5.0[d]	120	58
Noncatalytic	158,000	343,000	102,000	-1.0[d]	122	56

[a] Lower flow rate: 1,100 scfm for prime oven; 2,200 scfm for topcoat oven. Higher flow rate: 8,333 scfm for prime oven, 16,666 scfm for topcoat oven.

[b] Calculated from data for 5000 scfm using six-tenths rule.

[c] Based on 95 percent removal.

[d] Recovered energy is greater than energy input.

[e] Prime and Topcoat

15 percent of the LEL, incinerators can actually save energy by recovery of the fuel value from the solvents that would have been exhausted. This energy can displace natural gas or other fuels that otherwise would be needed for the oven, for metal cleaning, for building heat, or for other uses in the plant. Note that distillate oil as well as natural gas can be used as fuel for noncatalytic incinerators. Incinerators with higher heat recovery efficiency can be used to minimize fuel usage even of streams with lower LEL values.

6.4.6 Option 6 - Water-Borne Topcoats

Achievable Reductions - Reductions in organic solvent emissions of up to 92 percent from topcoat spray booths and ovens are achievable using water-borne topcoats. The exact reduction depends on both the original coating and the replacement. If, for example the original coating were 12 volume percent solids lacquer (6.5 lbs of organic solvent per gallon of coating) and the water-borne had 2.8 lbs of organic solvent per gallon of coating (as do GM coatings in California), reduction would be 92 percent. If the original coating were 33 volume percent solids, reduction would be 70 percent.

Technical Analysis - Water-borne topcoats are currently being used at two General Motors automobile assembly plants in California on a full-scale basis. Although there can be no argument as to the technical feasibility of water-borne topcoats, a number of major process modifications are necessary to retrofit this technology to an existing plant.[4,5] These are:

1. Lengthening of flash tunnel and ovens - Water-borne coatings require a longer flash tunnel prior to curing. Temperatures must also be raised more slowly in order to evaporate the water slowly enough to avoid pitting the coating. This necessitates longer ovens, which in turn may force equipment relocations.

2. Cleanliness - Water-borne coatings do not "touch dry" (dry to the point where the surface can be handled) as quickly as solvent-borne coatings. Thus they are more susceptible to dirt pick-up. This necessitates filtration of incoming spray booth air. Overhead conveyors may also be unacceptable because of potential for dropping dirt on newly painted parts.

3. Humidity and temperature - Because the major solvent being evaporated is water, proper temperature and humidity conditioning of the make-up spray booth air is vital. If the humidity is too high or the temperature too low, the solvent will not dry quickly enough and the coating will sag on vertical surfaces. If the humidity is too low or the temperature too high, the water will evaporate too rapidly and the coating will have "orange peel" or pits. Each coating must be formulated for a narrow humidity range, but formulations for different humidities (within limits) are possible. Water can be removed from incoming air by chemical or mechanical means. The chemical means involves the use of a hydroscopic solution. The mechanical means involves the use of refrigeration cycle. The most economical choice depends on both the climate and the availability of energy at the plant. The chemical method is more complex, but requires less energy.

The chemical method uses steam as its energy source while the mechanical method uses electricity. Thus, steam availability favors the chemical choice. Both methods have been used.[5]

4. Shutdown - Because of the potential for rusting and dirt pick-up, vehicles coated with water-borne coatings cannot be left wet overnight or even during shift change. The assembly line must have facilities for carrying painted vehicles through the following oven after a line shuts down. Accommodations must also be made for storage of these vehicles until the line starts up again. These requirements necessitate surge storage areas and independent conveyor chains for each of the spray booths with resultant controls and costs.

5. Cleanup - Unlike overspray from organic solvent-borne coating, water-borne coating overspray does not dry in the air before being drawn through the particulate collector. This causes increased cleanup problems and costs.

6. Sludge handling - Water-borne coatings do not harden in the water-wash particulate collectors, sludge handling is more difficult.

7. Corrosion - The pipe commonly used to convey organic solvent-borne coatings from central mixing areas to the spray booth are not suitable for water-borne coatings and must be replaced with a corrosion resistant material. The lifetime of carbon steel spray booths may also be lessened when water-borne coatings are used.

8. Maintenance - Maintenance costs will increase because of the new air conditioning and humidity control systems required.

9. Repair of coatings - Repair of coatings damaged during assembly is more difficult than for lacquers but no more difficult than for other enamels.

Cost of Control Option - The cost of converting to water-borne topcoats for an existing plant will vary. A major variable will be the age of the existing coating equipment. If near retirement, it may be better to build entirely new spray booths and ovens. This was done at one of two automobile plants which converted to water-borne coatings. In this case, costs should be adjusted to give credit for the value of the improved facilities.

If the coating equipment is still relatively modern, however, retrofitting will entail lengthening of ovens and modification of spray booths and conveyors. This was the approach taken at the other automobile plant using water-borne topcoats and is the basis for the cost calculations presented here. Capital costs for a switch to water-borne topcoats for the model plant are estimated to be about \$20 million.[5] For a plant where the entire coating line is replaced, capital costs are about twice this.[5]

Incremental operating costs include increased electrical requirements and increased maintenance labor. Coating material costs are approximately the same. Higher oven temperature causes an increase in natural gas usage. Annualized operating costs for the model are given in Table 6-6.

Effects and Limitations - The effluent water from water-borne coating processes will require the same treatment methods as that from solvent-borne systems. The treated effluent is acceptable to sewer authorities

TABLE 6-6. INCREASED ANNUAL OPERATING COST ESTIMATE FOR WATER-BORNE TOPCOATS OVER ORGANIC SOLVENT-BORNE TOPCOATS

Utilities: Electricity	$.03/KWhr x 4000hrs/yr x 5000KW	$600,000
Direct labor:	20 additional hrs/shift x 500 shifts/yr $15/hr	$150,000
Maintenance Building overhead Taxes and insurance Interest and depreciation[a]	21 percent x capital costs = 0.21 x $20,000,000	$4,200,000
Total increased operating cost		$4,950,000/yr

[a] Assuming a 20 year life and 10 percent interest charge

at the two California plants now using the coatings. Water-borne coatings do not precipitate and dewater as well in the overspray collection water as do some other paints and this lack of dewatering creates an increased solid waste disposal problem.

The additional electrical energy consumption to apply water-borne coatings is about 5000 KW. Since a typical plant uses about 12,000 KW, a change to water-borne topcoats increases electrical usage by 42 percent.

6.5 Comparison of Control Options and Conclusions

Prime Line - For prime application and cure, several control measures are applicable. Electrophoretic priming and water-borne surfacer is the most effective control system. The corrosion advantages of this system is such that at least one company is replacing their priming systems with electrophoretic systems as they are ready for replacement. Water-borne spray primer may also be used. Although emission reductions through increased solids content are more limited than for topcoats (enamels are very widely used), this option is worth consideration since there is still a substantial range of solids contents used. Incineration of ovens is effective and not energy intensive but it's benefit is limited since only 5-15 percent of the solvent evaporates there. Add-on devices for prime spray booths are technologically feasible but probably would not be installed because of the advantages of a transition to an electrophoretic coating.

Topcoat Line - Over two-thirds of uncontrolled emissions from the coating line come from the topcoat application and cure areas. Considerable reduction in emissions can be achieved at many plants by increasing the solids content. This is especially true for plants using lacquers. Incineration of an oven exhaust is effective for those emissions and energy consumption is minor if the resultant heat is recovered, but it has limited impact since only 5-15 percent of the solvent evaporates there. Carbon adsorption of spray booth exhaust is technically feasible but pilot studies are needed to overcome the difficulties. Incineration of spray booth exhaust is technically feasible but it uses substantial quantities of energy, even with good heat recovery. Water-borne topcoats are proven and reduce emissions considerably, but they are substantial users of electrical energy and require substantial capital investment. Unlike water-borne electrophoretic dip priming, there are no product quality advantages to the use of water-borne topcoats.

Generally, different control options require different lead times to implement and utilize the technology. The consideration of timing (the time by which reductions are sought) should be included in determining the degree of control required.

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APPENDIX A

APPENDIX A

ANALYTICAL TECHNIQUES

All analytical techniques used in the determination of compliance in the surface coating industry have previously been published by the American Society of Testing Materials (ASTM) or the U.S. Government Supply Agency. This Appendix details the applicability and procedures for using these methods. When used on certain coating products, however, the methods may yield erroneous results. Therefore, any emission control regulations which would rely on these methods should also provide authority for the source to request and the control agency to approve alternative techniques. During development of such alternatives, the source should be encouraged to coordinate with ASTM Committee D-1 which is responsible for the three ASTM test methods of interest, numbers D 1644-59, D 1475-60 and D 2369-73. The procedure that follows yields results in the units of mass per volume of coating. If units of mass per volume of solids are desired, the source should refer to ASTM test method D 2697-73.

DETERMINATION OF VOLATILE CONTENT OF PAINT, VARNISH, LACQUER, OR RELATED PRODUCTS

1. Principle and Applicability

1.1 Principle. The weight of nonaqueous volatile matter per unit volume of a paint, varnish, lacquer, or related surface coating is calculated after using standard methods to determine the density, nonvolatile matter content, and (if necessary) water content of the surface coating.

1.2 Applicability. This method is applicable to paint, varnish, lacquer, and related products, which are air-dried or force-dried; it is not applicable to any coating system which requires a special curing process such as exposure to temperatures in excess of 110°C to promote thermal cross-linking or exposure to ultraviolet light to promote cross-linking.

There may be other specific cases where the ASTM methods are not applicable. In general, these cases will occur when the evaporation temperature is so high as to produce thermal degradation of the nonvolatile matter in the surface coating or when the temperature is too low to produce complete evaporation of the volatile matter. The former will generally be indicated by a discoloration of the solid residue, while the latter will be indicated by incomplete drying of the residue (visible liquid or tackiness).

Whenever it is determined that the ASTM methods are not applicable, alternative methods subject to the approval of the State or local agency, must be used.

2. Classification of Surface Coatings

For the purposes of this method, the applicable surface coatings are divided into three classes. They are:

2.1 Class I: General Solvent-Type Paints. This class includes white linseed oil outside paint, white soya and phthalic alkyd enamel, white linseed o-phthalic alkyd enamel, red lead primer, zinc chromate primer, flat white inside enamel, white epoxy enamel, white vinyl toluene modified alkyd, white amino modified baking enamel, and other solvent-type paints not included in Class II.

2.2 Class II: Varnishes and Lacquers. This class includes clear and pigmented lacquers and varnishes.

2.3 Class III: Water Thinned Paints. This class includes emulsion or latex paints and colored enamels.

3. Applicable Standard Methods

3.1 ASTM D 1644-59 Method A: Standard Methods of Test for Nonvolatile Content of Varnishes. Do not use Method B.

3.2 ASTM D 1475-60: Standard Method of Test for Density of Paint, Varnish, Lacquer, and Related Products.

3.3 ASTM D 2369-73: Standard Method of Test for Volatile Content of Paints.

3.4 Federal Standard 141a, Method 4082.1: Water in Paint and Varnishes (Karl Fischer Titration Method).

4. Procedure

4.1 Classification of Samples. Assign the coating to one of the three classes discussed in Section 2 above. Assign any coating not clearly belonging to Class II or III to Class I.

4.2 Analyses and Calculations. Determine the density D_m (in g/cm^3) of the paint, varnish, lacquer, or related product according to the procedure outlined in ASTM D 1475-60. Then, depending on the class of the coating, use one of the following specified procedures to determine the volatile content:

4.2.1 Class I. Use the procedure in ASTM D 2369-73; record the following information:

W_1 = Weight of dish and sample, g.

W_2 = Weight of dish and sample after heating, g.

S = Sample weight, g.

Calculate the volatile matter content C_v (in g/l of paint) as follows:

$$C_v = \frac{(W_1 - W_2)(D_m)(10^3)}{S}$$

To convert g/l to lb/gal, multiply C_v by 8.3455×10^{-3}.

4.2.2 Class II. Use the procedure in ASTM D 1644-59 Method A; record the following information:

A = Weight of dish, g.

B = Weight of sample used, g.

C = Weight of dish and contents after heating, g.

Calculate the volatile matter content C_v (in g/l) as follows:

$$C_v = \frac{(A + B - C)(D_m)(10^3)}{B}$$

To convert g/l to lb/gal, multiply C_v by 8.3455×10^{-3}.

4.2.3 Class III. Use the procedure in ASTM D 2369-73; record the same information as specified in Section 4.2.1. Determine the water content P (in percent water) of the paint according to the procedure outlined in Federal Standard 141a, Method 4082.1. Calculate the nonaqueous volatile matter content C_v (in g/l) as follows:

$$C_v = \frac{(W_1 - W_2 - 0.01\ PS)(D_m)(10^3)}{S}$$

To convert g/l to lb/gal, multiply C_v by 8.3455×10^{-3}.

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APPENDIX B

RECOMMENDED POLICY ON CONTROL OF VOLATILE ORGANIC COMPOUNDS

ENVIRONMENTAL PROTECTION AGENCY

Air Quality

RECOMMENDED POLICY ON CONTROL OF VOLATILE ORGANIC COMPOUNDS

PURPOSE

The purpose of this notice is to recommend a policy for States to follow on the control of volatile organic compounds (VOC), which are a constituent in the formation of photochemical oxidants (smog). This notice does not place any requirements on States; State Implementation Plan (SIP) provisions which offer reasonable alternatives to this policy will be approvable. However, this policy will be followed by EPA whenever it is required to draft State Implementation Plans for the control of photochemical oxidants.

BACKGROUND

Photochemical oxidants result from sunlight acting on volatile organic compounds (VOC) and oxides of nitrogen. Some VOC, by their nature, start to form oxidant after only a short period of irradiation in the atmosphere. Other VOC may undergo irradiation for a longer period before they yield measurable oxidant.

In its guidance to States for the preparation, adoption, and submittal of State Implementation Plans published in 1971, the Environmental Protection Agency emphasized reduction of total organic compound emissions, rather than substitution. (See 40 CFR Part 51, Appendix B.) However, in Appendix B, EPA stated that substitution of one compound for another might be useful where it would result in a clearly evident decrease in reactivity and thus tend to reduce photochemical oxidant formation. Subsequently, many State Implementation Plans were promulgated with solvent substitution provisions similar to Rule 66 of the Los Angeles County Air Pollution Control District. These regulations allowed exemptions for many organic solvents which have now been shown to generate significant photochemical oxidant.

On January 29, 1976, EPA published its "Policy Statement on Use of the Concept of Photochemical Reactivity of Organic Compounds in State Implementation Plans for Oxidant Control." The notice of availability of this document appeared in the FEDERAL REGISTER on February 5, 1976 (41 FR 5350).

The 1976 policy statement emphasized that the reactivity concept was useful as an interim measure only, and would not be considered a reduction in organic emissions for purposes of estimating attainment of the ambient air quality standard for oxidants. The document also included the following statement:

> Although the substitution portions of Rule 66 and similar rules represent a workable and acceptable program at the present time, better substitution regulations can be developed, based on current knowledge of reactivity and industrial capability. EPA in collaboration with State and industry representatives will formulate in 1976 an improved rule for national use.

SUMMARY

Analysis of available data and information show that very few volatile organic compounds are of such low photochemical reactivity that they can be ignored in oxidant control programs. For this reason, EPA's recommended policy reiterates the need for positive reduction techniques (such as the reduction of volatile organic compounds in surface coatings, process changes, and the use of control equipment) rather than the substitution of compounds of low (slow) reactivity in the place of more highly (fast) reactive compounds. There are three reasons for this. First, many of the VOC that previously have been designated as having low reactivity are now known to be moderately or highly reactive in urban atmospheres. Second, even compounds that are presently known to have low reactivity can form appreciable amounts of oxidant under multiday stagnation conditions such as occur during summer in many areas. Third, some compounds of low or negligible reactivity may have other deleterious effects.

Of the small number of VOC which have only negligible photochemical reactivity, several (benzene, acetonitrile, chloroform, carbon tetrachloride, ethylene dichloride, ethylene dibromide, and methylene chloride) have been identified or implicated as being carcinogenic, mutagenic, or teratogenic. An additional compound, benzaldehyde, while producing no appreciable ozone, nevertheless, forms a strong eye irritant under irradiation. In view of these circumstances, it would be inappropriate for EPA to encourage or support increased utilization of these compounds. Therefore, they are not recommended for exclusion from control. Only the four compounds listed in Table 1 are recommended for exclusion from SIP regulations and, therefore, it is not necessary that they be inventoried or controlled. In determining reductions required to meet oxidant NAAQS, these VOC should not be included in the base line nor should reductions in their emission be credited toward achievement of the NAAQS.

It is recognized that the two halogenated compounds listed in Table 1 (methyl chloroform and Freon 113) may cause deterioration of the earth's ultraviolet radiation shield since they are nearly unreactive in the lower atmosphere and all contain appreciable fractions of chlorine. The Agency has reached conclusions on the effects of only the fully halogenated chlorofluoroalkanes. The Agency on May 13, 1977 (42 FR 24542), proposed rules under the Toxic Substances Control Act (TSCA) to prohibit the nonessential use of fully halogenated chlorofluoroalkanes as aerosol propellants. The restrictions were applied to all members of this class, including Freon 113, since they are potential substitutes for Freon 11, Freon 12, Freon 114, and Freon 115, which are currently used as aerosol propellants. The Agency is planning to investigate control systems and substitutes for nonpropellant uses under TSCA, as announced on May 13. Methyl chloroform is not a fully halogenated chlorofluoroalkane. Rather, it is among the chlorine-containing compounds for which the Agency has not completed its analysis; EPA has not yet concluded whether it is or is not a threat to the stratospheric ozone. Therefore, it has been placed on this list as an acceptable exempt compound. As new information becomes available on these compounds, EPA will reconsider the recommendation.

The volatile organic compounds listed in Table 2, while more photochemically reactive than those in Table 1, nevertheless do not contribute large quantities of oxidant under many atmospheric conditions.

Table 1

Volatile Organic Compounds of Negligible Photochemical Reactivity That Should Be Exempt From Regulation Under State Implementation Plans

Methane

Ethane

*1,1,1-Trichloroethane (Methyl Chloroform)

*Trichlorotrifluoroethane (Freon 113)

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*These compounds have been implicated as having deleterious effects on stratospheric ozone and, therefore, may be subject to future controls.

Table 2

Volatile Organic Compounds of Low Photochemical Reactivity

Propane

Acetone

Methyl Ethyl Ketone

Methanol

Isopropanol

Methyl Benzoate

Tertiary Alkyl Alcohols

Methyl Acetate

Phenyl Acetate

Ethyl Amines

Acetylene

N, N-dimethyl formamide

Only during multiday stagnations do Table 2 VOC yield significant oxidants. Therefore, if resources are limited or if the sources are located in areas where prolonged atmospheric stagnations are uncommon, priority should be given to controlling more reactive VOC first and Table 2 organics later. Table 2 VOC are to be included in base line emission inventories and reductions in them will be credited toward achievement of the NAAQS. Reasonably available control technology should be applied to significant sources of Table 2 VOC where necessary to attain the NAAQS for oxidants. New sources of these compounds will also be subject to new source review requirements.

Perchloroethylene, the principal solvent employed in the dry cleaning industry, is also of low reactivity, comparable to VOC listed in Table 2. It was not included in Table 2 because of reported adverse health effects. Uses, environmental distribution, and effects of perchloroethylene currently are being studied intensively by occupational health authorities and EPA. Findings from these investigations may have major impact on industrial users. In designing control regulations for perchloroethylene sources, particularly dry cleaners, consideration should be given to these findings as well as industry requirements and the costs of applying controls. Available control technology is highly cost effective for large perchloroethylene dry cleaning operations. However, for coin-operated and small dry cleaners, the same equipment would represent a heavy economic burden.

As part of its continuing program, EPA will review new information relative to the photochemical reactivity, toxicity, or effects on stratospheric ozone of volatile organic compounds. Where appropriate, additions or deletions will be made to the lists of VOC in Tables 1 and 2.

DISCUSSION

Most air pollution control regulations applicable to stationary sources of VOC in the United States are patterned after Rule 66 of the Los Angeles County Air Pollution Control District (presently Regulation 442 of the Southern California Air Pollution Control District). Rule 66 and similar regulations incorporate two basic strategies to reduce ambient oxidant levels, i.e., positive VOC reduction and selective solvent substitution based on photochemical reactivity. Positive reduction schemes such as incineration, adsorption, and the use of low-solvent coatings are acknowledged means of reducing ambient oxidant levels; they should be retained in future VOC control programs. In contrast, the utility of solvent substitution strategies has been questioned as more information on photochemical reactivity has emerged.

EPA acknowledged the shortcomings of solvent substitution based on Rule 66 reactivity criteria in a 1976 policy statement (41 FR 5350). Findings were cited which indicated that almost all VOC eventually react in the atmosphere to form some oxidant. Concurrently, EPA initiated an investigation to consider implications of revising the solvent substitution aspects of Rule 66. Three separate forums were conducted with representatives of State and local air pollution control agencies, university professors, and industrial representatives with knowledge and expertise in the fields of atmospheric chemistry and industrial solvent applications. In addition, numerous discussions were held with acknowledged experts in the field. Topics of particular concern were:

- Whether Rule 66 substitution criteria could be revised consistent with available reactivity data and yet be compatible with industrial processes and with product requirements.
- Whether some compounds are of sufficiently low reactivity that they are not oxidant precursors and can be exempted from control under State Implementation Plans.
- Whether the imposition of reactivity restrictions in addition to positive emission reductions will delay the development or implementation of promising technologies, particularly the use of water-borne and high-solids surface coatings.

Investigation showed that:

1. Solvent substitution based on Rule 66 has been directionally correct in the aggregate and probably effects some reductions in peak oxidant levels. However, because of the relatively high reactivity of most of the substituted solvents, the reduction is small compared to that which can be accomplished with positive reduction techniques. Revision of Rule 66 consistent with current knowledge of reactivity would eliminate the solvent substitution option for most sources in which substitution is now employed. Many of the organic solvents which have been categorized as having low photochemical reactivity are, in fact, moderately or highly reactive; they yield significant oxidant when subjected to irradiation in smog chambers designed to simulate the urban atmosphere.

2. A few VOC yield only negligible ozone when irradiated in smog chambers under both urban and rural conditions. Experiments conducted to date indicate that only methane and ethane, a group of halogenated paraffins, and three other organics--benzene, benzaldehyde, and acetonitrile--can be so classified. These compounds react very slowly yielding little ozone during the first few days following their release to the atmosphere. Available data suggest that none of the listed compounds contribute significant oxidant even during extended irradiation under multiday stagnation conditions.

The broad group "halogenated paraffins" includes important industrial solvents, most of which are chlorinated methanes and ethanes and chlorofluoroethanes. They find use as metal cleaning and dry cleaning solvents and as paint removers. Halogenated paraffins also serve as building blocks in the manufacture of other halogenated organics; these processes do not necessarily release significant VOC to the atmosphere.

3. Besides focusing on VOC of negligible reactivity, smog chamber studies show that a few additional VOC generate oxidant at a relatively slow rate. Under favorable atmospheric conditions, these VOC releases may not form oxidant until they have been transported substantial distances and become greatly diluted. However, under multiday stagnation conditions such as occur during summer in many areas of the middle and eastern United States, there is the potential for these organics to undergo appreciable conversion to oxidant. The more important VOC in this category are acetone, methyl ethyl ketone, perchloroethylene, methanol, isopropanol, and propane. All except propane are industrial

solvents. The latter, a gas under normal conditions, is associated principally with crude oil and liquefied petroleum gas operations.

4. The vast number of volatile organic compounds--particularly nonhalogenated VOC--yield appreciable ozone when irradiated in the presence of oxides of nitrogen. While there are measurable variations in their rates of ozone formation, all are significantly more reactive than VOC listed in Table 2. Quickly reactive VOC include almost all aliphatic and aromatic solvents, alcohols, ketones, glycols, and ethers.

5. Low photochemical reactivity is not synonymous with low biological activity. Some of the negligible or slowly reactive compounds have adverse effects on human health. Benzene, acetonitrile, carbon tetrachloride, chloroform, perchloroethylene, ethylene dichloride, ethylene dibromide, and methylene chloride have been implicated as being carcinogens, teratogens, or mutagens. In addition, benzaldehyde, which produces no appreciable ozone, nevertheless forms a strong eye irritant under irradiation. While their use might reduce ambient oxidant levels, it would be unwise to encourage their uncontrolled release. Additional halogenated organics are being investigated for possible toxicity.

Most of the related health information available at this time concerns acute toxicity. Threshold limit values (TLV's) have been developed for many VOC. They are appropriate for the healthy, adult work force exposed eight hours a day, five days a week. Experts suggest that more stringent levels should be established for the general population. Hazards represented by chronic and subchronic exposure are much more difficult to quantify than acute toxicity. Adverse health effects of the VOC cited above are generally recognized although not completely quantified. Chlorinated solvents currently are under intensive study.

6. Some VOC are of such low photochemical reactivity that they persist in the atmosphere for several years, eventually migrating to the stratosphere where they are suspected of reacting and destroying ozone. Since stratospheric ozone is the principal absorber of ultraviolet (UV) light, the depletion could lead to an increase in UV penetration with a resultant worldwide increase in skin cancer. The only in-depth analysis of this potential problem has focused on the chlorofluoromethanes (CFM), Freon 11 and Freon 12, because of their known stability and widespread use in aerosol containers. A report of the National Academy of Sciences concerning environmental effects of CFM's concluded that:

> ". . . selective regulation of CFM uses and releases is almost certain to be necessary at some time and to some extent of completeness."

In response to the report of the National Academy of Sciences and other studies, EPA on May 13, 1977 (42 FR 24542) proposed rules to prohibit nonessential usage of fully halogenated chlorofluoroalkanes as aerosol propellants. The restrictions were applied to all members of this class including Freon 113 since they are potential substitutes for Freon 11, Freon 12, Freon 114, and Freon 115 which are currently used as aerosol propellants.

Other stable halogenated solvents which are released in volumes comparable to the chlorofluoroalkanes also are suspected of depleting the earth's UV shield. Of major concern is the widespread substitution of methyl chloroform (1,1,1 trichloroethane) for the photochemically reactive degreasing solvent trichloroethylene. Such substitution under Rule 66 generation regulations has already influenced industrial degreasing operations to the extent that methyl chloroform production has surpassed that of trichloroethylene in the United States. Any regulation in the area will have a marked effect on the production and atmospheric emissions of both solvents. Endorsing methyl chloroform substitution would increase emissions, particularly in industrial States that have not, heretofore, implemented Rule 66. On the other hand, disallowing methyl chloroform as a substitute or banning it altogether would significantly increase emissions of trichloroethylene even if degreasers were controlled to the limits of available technology. Presently, technology is only able to reduce emissions by approximately 50 percent. In metropolitan areas which have already implemented Rule 66, a return to trichloroethylene would have an adverse effect on ambient oxidant levels. In addition to being highly reactive, trichloroethylene has been implicated as a carcinogen.

Alternatives to the above-cited choices would be (1) development and application of highly efficient degreaser control systems and (2) replacement with an intermediate solvent which is neither reactive nor detrimental to the upper atmosphere. Major revisions would be needed to degreaser designs to improve vapor capture above the current best level. Anticipated design changes could add materially to degreaser costs. No alternative solvent is clearly acceptable from the standpoints of photochemical oxidant and stratospheric ozone depletion. Neither methylene chloride nor trichlorotrifluoroethane are reactive, but, like methyl chloroform, are suspected of causing damage to the stratospheric ozone layer. In addition, methylene chloride is a suspect mutagen. Perchloroethylene, the principal dry cleaning solvent, does not present a hazard to the stratosphere but has been implicated as being a carcinogen and also reacts slowly in the atmosphere to form oxidant.

7. Organic solvents of low or negligible photochemical reactivity have only limited use in many industries. Most are chlorinated organics that find principal applications as cleaners for metals and fabrics. A few nonhalogenated VOC such as acetone, methyl ethyl ketone, and isopropanol are of low reactivity but these can't possibly satisfy all the myriad needs of the paint, plastics, pharmaceutical, or many other industries. While users of reactive VOC usually can employ effective control equipment to recover or destroy VOC emissions, they seldom have the option of applying reactivity considerations in choosing solvents. Applying reactivity restrictions to the surface coating industry would be especially disadvantageous since it would greatly inhibit the development of low-solvent coatings; essentially all of the organic solvents used to constitute high-solids coatings and water-borne coatings are, in fact, highly reactive.

8. It is recognized that smog chamber studies conducted to date are incomplete because many organic compounds have not been examined and it has been impossible to duplicate all atmospheric situations. For example, there has been only limited examination of oxidant formation under relatively high ratios of VOC to NO_x (30:1 and greater), comparable to rural conditions. Any policy on photochemical reactivity necessarily

has to be open to revision as new information is developed which may show specific organic compounds to be more or less photochemically reactive than indicated by current data.

Dated: ______________________________

____

Acting Assistant Administrator
for Air and Waste Management

APPENDIX C

REGULATORY GUIDANCE

1. INTRODUCTION

This section serves to facilitate the preparation of regulations for the control of volatile organic compound (VOC) emissions from the surface coating operations discussed in this document. This guidance is not intended to prescribe specific regulatory language. Responsibility for developing regulations and the associated emission limitations clearly rests with the respective States.

2. GENERAL DISCUSSION

The recommended regulatory approach is predicated on the concept of positive emission reduction rather than the substitution of compounds of lower reactivity as the means of reducing ambient levels of photochemical oxidant. This is in keeping with EPA's recent policy statement on reactivity.

The facility to be controlled in each of the five coating operations discussed in this document is the coating line. In general, the recommended control approach is to reduce emissions from the coating line by means of low solvent coating technology. This approach is recommended since, in addition to reducing emissions at the applicator, it also serves to reduce fugitive and flash area emissions while at the same time eliminating the need for add-on control equipment. It should be recognized, however, that for certain source categories or coating lines it may be preferable to use add-on controls, particularly when heat or VOC recovery techniques can be employed. Therefore, the regulations should not preclude the employment of add-on devices such as incinerators and adsorbers with appropriate capture systems.

Before developing regulations, States should carefully evaluate the sources to be regulated within their jurisdiction to determine whether the emission limitations cited in this document truly reflect reasonably available control technology (RACT)[1] for them. In some instances, it may be found that the guidance is not appropriate for a particular coating material or coating operation.

The employment of low solvent coatings may be technology forcing for certain products or applications. Under such circumstances, an extended time period may be required to evaluate the low solvent coatings both in the laboratory and the field, prior to placing them into production. In comparison, the application of add-on control devices is well demonstrated and the only constraint is the time necessary to purchase, install, and start up such equipment. In view of these factors, compliance schedules should be flexible, taking into consideration the specific problems associated with a given plant. Consideration may also have to be given to the cumulative impact of other jurisdictions promulgating similar regulations, which may limit the availability of control equipment, etc.

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[1] Reasonably available control technology (RACT) is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical, source categories. It is not intended that extensive research and development be conducted before a given control technology can be applied to the source. This does not, however, preclude requiring a short-term evaluation program to permit the application of a given technology to a particular type of source. This latter effort is a legitimate technology-forcing aspect of RACT.

Even though the regulatory requirements are based on control technology that has been determined to be reasonably available for the source category as a whole, some individual plants may not be able to comply with them. In order to forestall future problems of compliance, the States should review their various authorities at the time regulations are developed. If it is found that existing authorities do not provide sufficient flexibility to accommodate such problems, consideration should be given to developing regulatory provisions which will provide adequate relief.

To assist in developing regulations, the Office of Air Quality Planning and Standards (OAQPS) has identified several areas that should be taken into consideration. These are discussed below.

Common Terminology

When developing regulations it is important that a degree of commonality exists in the definition of key terms. This will provide a greater degree of understanding on the part of source owners and operators and remove some of the confusion that presently exists for owners that have multi-State operations. With this in mind, the following definitions were developed for commercial and industrial surface coating operations:

a. Coating applicator means an apparatus used to apply a surface coating.

b. Oven means a chamber within which heat is used to bake, cure, polymerize, and/or dry a surface coating.

c. Coating line means one or more apparatus or operations comprised of a coating applicator, flash-off area, and oven wherein a surface coating is applied, dried, and/or cured.

d. Owner or operator means any person who owns, leases, operates, controls, or supervises a surface coating operation or a __________ plant of which a surface coating operation is a part.

e. Standard conditions mean a temperature of 20°C (68°F) and pressure of 760 mm of Hg (29.92 inches of Hg).

f. Volatile organic compound is any compound of carbon (excluding carbon monixide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate) that has a vapor pressure greater than 0.1 mm of Hg at standard conditions.

g. Day means a 24 hour period beginning at midnight.

h. Capture system means the equipment (including hoods, ducts, fans, etc.) used to contain, capture, or transport a pollutant to a control device.

i. Control device means equipment (incinerator, adsorber, or the like) used to destroy or remove a pollutant from a discharge gas stream.

j. Approved means approved by the designated air pollution control official.

Expression of Requirements

When developing regulations, the language used to express the requirement must be carefully weighed. As noted on page 1-5, the decision to express emission limitations for coating operations in terms of weight of VOC per volume of coating, less water, was chosen after much deliberation. A change in the manner of expression without an adjustment in the limit could materially affect the stringency of the requirements. Therefore, if it is found desirable to express the limitation in different terms, such as pound of VOC per pound of coating solids, reference should be made to Appendix D so the recommended emission limit can be properly adjusted.

Similar care must be exercised when specifying requirements for incinerators and other add-on control devices. At present, there are no standardized test methods that can be universally applied to determine mass rates of emission or concentrations of VOC. In view of this, requirements for incinerators and most other add-on devices should be expressed in terms of efficiency of removing organics expressed as combustible carbon.

In view of the above, OAQPS developed the following language for expressing an emission limitation based on the guidance contained in this document:

"No owner or operator subject to the provisions of this regulation shall discharge or cause the discharge into the atmosphere from a coating line any volatile organic compound in excess of ______ pounds per gallon of coating, excluding water, delivered to the coating applicator.

"The emission limit prescribed above shall be achieved by:

a. Low solvent coating technology,

b. Incineration, provided that 90 percent of non-methane volatile organic compounds (VOC measured as total carbon) which enter the incinerator are oxidized to carbon dioxide and water; or

c. Processing the discharge in a manner determined by control official to be not less effective than that of b obove."

When providing for the use of add-on devices as a means of complying with the requirements of the regulation, the States should also require that such control devices be equipped with an approved capture system in order to assure effective control. When examining the need for such a provision, OAQPS staff explored whether it was feasible to prescribe performance or design specifications for capture systems. After examining the situation, it was concluded that effective capture systems must be custom designed to accommodate plant-to-plant variables which affect performance. An alternative approach of testing to determine whether VOC is escaping capture was also dismissed for the want of suitable testing techniques. In view of these findings, it is recommended that case-by-case design review be performed to assure installation of effective capture systems.

When reviewing capture system designs, air pollution officials must take into consideration requirements imposed by the Occupational Safety and Health Administration and the National Fire Prevention Association, as well as State and local health and safety officials. The publication "Industrial Ventilation, A Manual of Recommended Practice" prepared by the American Conference of Governmental Industrial Hygienists is one source of guidance on the proper design of capture and ventilation systems.

Need for Flexibility

As was discussed earlier, the employment of low solvent coatings may be technology forcing for certain products or applications. Under such circumstances additional time should be afforded sources faced with real technological problems, provided they move as expediently as practicable toward compliance. During this period it may be appropriate for the State to require interim controls such as solvent substitution. OAQPS does not necessarily recommend the installation of add-on control devices, particularly incinerators, if the interim period is to be of relatively short duration. In many instances, to do so would be a disincentive for the source to continue its efforts to develop low solvent coatings.

An alternate approach that has been the subject of discussion is to allow the source to develop a plant-wide emission reduction plan. Under such an approach, the source owner would have to demonstrate that any emissions in excess of those allowed for a given coating line would be compensated for. Compensation would be achieved by either reducing VOC emissions from other coating lines below the allowable level or by controlling non-regulated sources within the surface coating facility. The plant-wide emission reduction plan provides flexibility by affording the source owner the opportunity to select the most cost-effective means of providing the desired VOC reduction. In addition, it promotes innovation by encouraging the control of sources that have not been previously regulated and by providing the source owner an incentive to control certain coating lines to a greater degree than that required by the emission limitation. While this approach has been favorably viewed by industry, enforcement officials have expressed reservations as to its enforceability. If the problems of enforceability can be overcome, the plant-wide emission reduction approach would appear to be a very useful tool.

Seasonal Operation of Natural Gas-Fired Afterburners

As an energy conservation measure, it is also recommended that provision be made for the seasonal operation of natural gas-fired afterburners. The basic rationale for seasonal operation of natural gas-fired afterburners and the criteria for designating time periods within which the devices may be shut down was set forth in the July 28, 1976, policy statement "Seasonal Operation of Natural Gas-Fired Afterburners" issued by the Assistant Administrator of Air and Waste Management (see attachment). The following language is offered if a State determines that the best method of implementing this policy is by incorporation into its regulation:

"The operation of natural gas-fired incinerator and associated capture systems installed for the purpose of complying with this regulation will not be required in (specify AQCR) during the month (or months) of _________ provided that the operation of such devices is not required for purposes of occupational health or safety or for the control of toxic substances, malodors, or other regulated pollutants."

Disposal of Waste VOC

Consideration should also be given to restricting the manner by which waste volatile organic compounds are disposed. To accomplish this objective, OAQPS suggests the following regulatory language:

"No owner or operator shall dispose of or permit the disposal of more than _______ gallons per day of volatile organic compounds by any means which will permit the evaporation of such compounds to the atmosphere."

Small Source Exemption

States should also consider for inclusion in their regulation a provision to exempt certain coating lines from control due to their small quantity of emissions. When determining which coating lines to exempt, States should assess the sources within their jurisdiction to determine a lower cut off level which will result in the most effective control strategy.

Finally, when developing regulations the States should be cognizant of EPA policy statements and other guidance on overall strategy for oxidant control such as photochemical reactivity, seasonal control, and the prioritization of geographical areas for which reductions in volatile organic emissions are required.

ATTACHMENT

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUL 28 1976

OFFICE OF
AIR AND WASTE MANAGEMENT

SUBJECT: Seasonal Operation of Natural
Gas-Fired Afterburners

MEMO TO: Regional Administrators

It has been estimated that the use of afterburners for control of air pollutants required 0.4 percent of the total 22 trillion cubic feet of natural gas consumed in 1975 in the U.S.. While not a high percentage, this is a substantial amount of natural gas--equivalent, for example, to the annual amount required to heat 62,000 homes in Washington, D.C.

Many of these afterburners are required solely to reduce emissions of hydrocarbons to control ambient oxidant levels. However, results from both statistical analyses of ambient data and smog chamber tests show that oxidants do not readily form at temperatures below about 59°F. Thus, in many parts of the U.S., the operation of afterburners required for oxidant control may not be needed during the winter months. This fact and the expectation that natural gas will be in short supply during the coming winter support an EPA policy of allowing states to permit natural gas-fired afterburners to be shut down during the coming winter season provided there is reasonable assurance that this action will not jeopardize the attainment or maintenance of the oxidant standard. The situation in future winters should be evaluated in light of then-existing circumstances.

The policy applies to gas-fired afterburners installed to control hydrocarbon emissions for the purpose of reducing ambient oxidant concentration. It does not apply to flares (which do not use gas as an auxiliary fuel), hydrocarbons vented to boilers, afterburners operated principally for odor control, or afterburners operated to control toxic substances. Some afterburners which control hydrocarbon emissions also control, either primarily or secondarily, the emissions of carbon monoxide and particulate matter. The seasonal shutoff of some of these also could be permitted if neither the attainment nor the maintenance of the ambient standards for those pollutants is jeopardized.

Measurements of oxidant air quality indicate that ambient concentrations diminish substantially in many northern areas during the winter; northern urban areas in which summertime oxidant concentrations often exceed the national standard by large amounts experience greatly reduced concentrations during the winter season. This observed seasonal phenomenon is consistent with the theory of oxidant formation; high ambient temperatures and strong sunlight assist in the production of oxidants from a complex photochemical reaction involving hydrocarbons and nitrogen oxides.

A recent analysis of oxidant air quality data and meteorological data* identifies areas of the country which, during specified months, experience low oxidant concentrations. This analysis shows a high correlation between maximum daily temperatures and maximum hourly oxidant concentrations, with concentrations above the national standard becoming highly improbable when maximum daily temperatures are consistently below 59°F. The analysis suggests that the maximum daily temperature can be used as a reasonably reliable indicator of the potential for oxidant formation and supports a policy which would permit seasonal use of natural gas-fired afterburners in many areas.

Figure 1 is a map of the U.S. on which study results are summarized. It shows general areas (or zones) in which seasonal shutoff of natural gas-fired afterburners could be considered. However, it is important to note that local conditions may obviate seasonal control even though shutdown otherwise may appear to be acceptable. If, for example, wintertime oxidant concentrations in a particular area are in violation of the ambient standard, or the concentrations are sufficiently high that afterburner shutdown could create violations, you should neither encourage nor allow seasonal afterburner operation even though the area is in a theoretically acceptable zone.

A policy to seasonally control afterburners can only be implemented through the SIP process -- by establishing new oxidant SIPs or by revising existing SIPs. Of course, the enforceability of the policy must be carefully considered in reviewing each specfic regulation. The approval of SIP changes to permit seasonal afterburner operation need not require detailed, time-consuming analyses of air quality impacts if the seasonal shutdown time period is consistent with the zones delineated in Figure 1, and if existing air quality data shows no past violations in the month during which the afterburners will be shutdown. The attached staff study, supported by air quality data where available, normally should be adequate technical support for a decision to approve the seasonal operation of afterburners in a given location. If an occasional high oxidant concentration has been noted during the winter months but the gas savings to be achieved by afterburner shutoff appears to warrant favorable consideration of a variance request, a short trial period to test the impact on oxidant concentrations may be suggested. If it is found that ambient violations persist or are exacerbated, the trial program must be terminated.

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*See attached OAQPS "Staff Study: Oxidant Air Quality and Meteorology," dated February 6, 1976.

It is recommended that you notify those state agencies in your Region which may be eligible to implement this program that EPA supports a policy which would permit sources to shut off afterburners during cold weather months this year when oxidant concentrations are below the ambient standard. In discussing this policy with state agency personnel, it is important to emphasize that the policy pertains only to oxidant control strategy and that EPA is not encouraging a wide-spread increase in hydrocarbon emissions. Moreover you must make it clear that, consistent with §116 of the Clean Air Act, the state is not required in any way to relax its strategy.

Roger Strelow

Roger Strelow
Assistant Administrator
for Air and Waste Management

Enclosure

cc: Stan Legro
William Frick

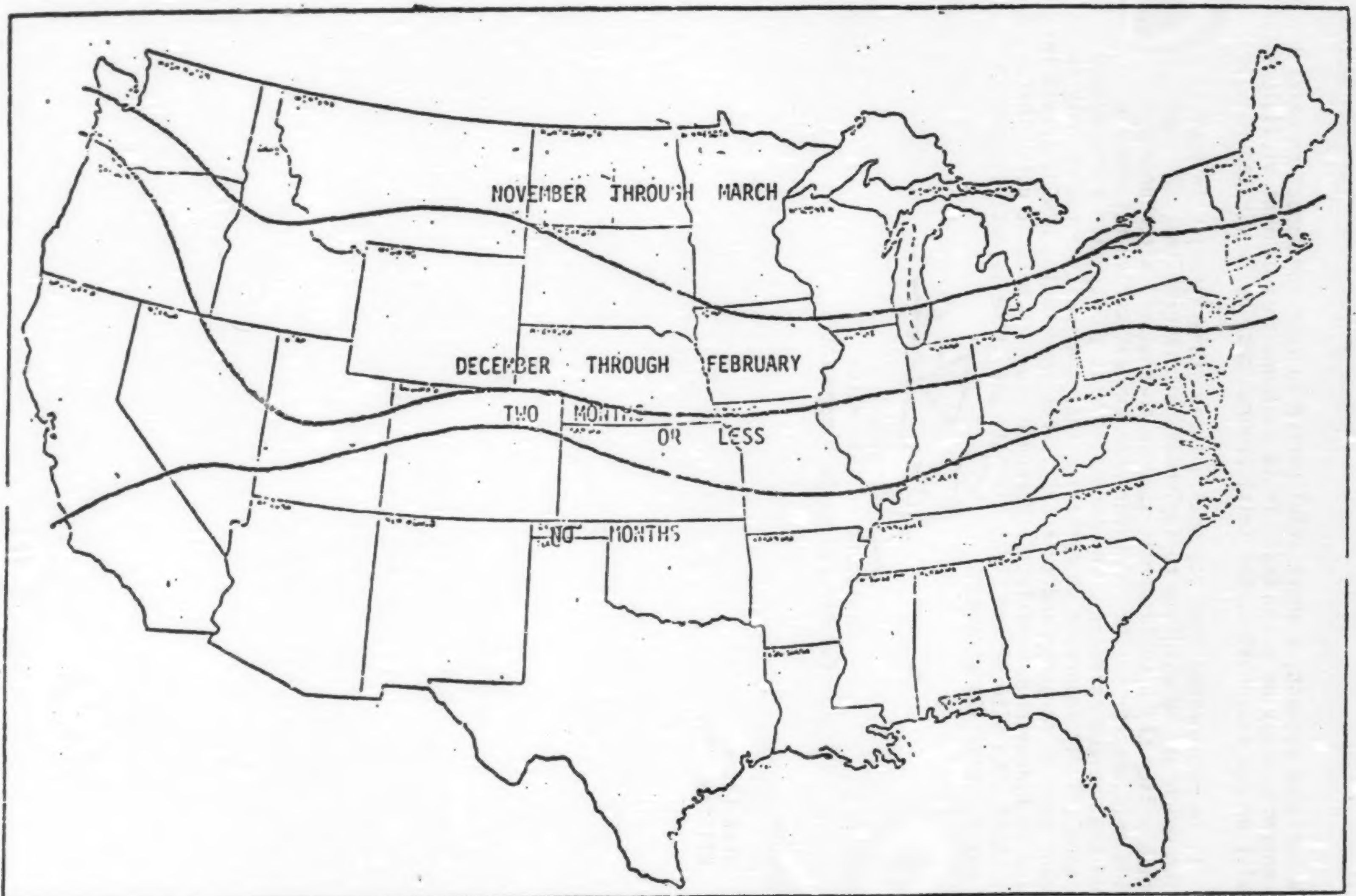

NOVEMBER THROUGH MARCH
DECEMBER THROUGH FEBRUARY
TWO MONTHS OR LESS
NO MONTHS

Figure 1. Areas for Which the Probability of Maximum Daily Temperature > 59°F is < 5% During Monthly Ranges Indicated (Based on 5 Years of Temperature Data).

STAFF STUDY: OXIDANT AIR QUALITY AND METEOROLOGY

February 6, 1976

Prepared By

Monitoring and Reports Branch
Monitoring and Data Analysis Division
Office of Air Quality Planning and Standards

C-13

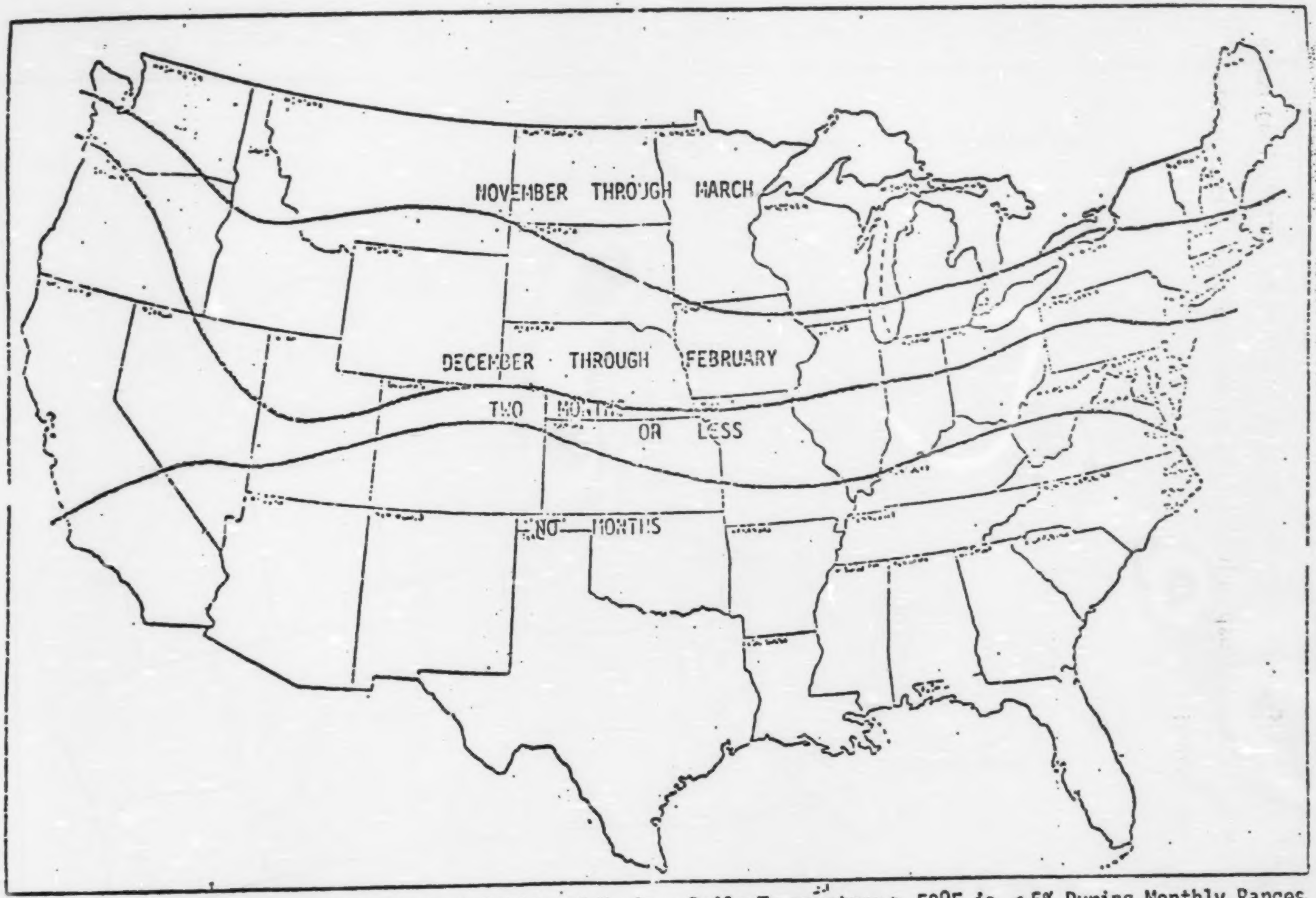
Oxidant Air Quality and Meteorology

An analysis was performed of the seasonal variation of days with violations of the oxidant standard at sites across the nation with sufficient data for all four quarters of 1974. Depicted in Figures 2 through 4 are the percent of days with hourly concentrations exceeding the NAAQS of 160 mg/m^3 for three periods: (1) Dec-Jan-Feb; (2) Nov-Dec-Jan-Feb-Mar; and, (3) Apr through Oct. The analysis shows conclusively that for the two sets of monthly ranges during the cold season, oxidant NAAQS violations decrease substantially from the warmer months. This is consistent with the seasonal cycle of temperatures and solar radiation that has a pronounced effect on ozone synthesis.

Air quality data for some states were not available in EPA's data bank. Also, in some states only a few monitoring sites had sufficient data for all quarters or those stations with sufficient amounts of data may not have been located where maximum concentrations occur. Therefore, because of some deficiencies inherent in the air quality data base, an additional parameter was used as an indicator of significant ozone formation potential. This parameter, maximum daily temperature, was used as a surrogate for ambient ozone data in areas without such data and as a supplement in areas with insufficient data. High maximum daily temperatures have been associated with high ozone concentrations in field and smog chamber studies.[1, 2, 3] Our best estimate is that nearly all oxidant/ozone concentrations above the NAAQS occur with maximum daily temperatures above about 58-59°F. This was corroborated by an independent analysis of 1973 ozone/oxidant data.[4]

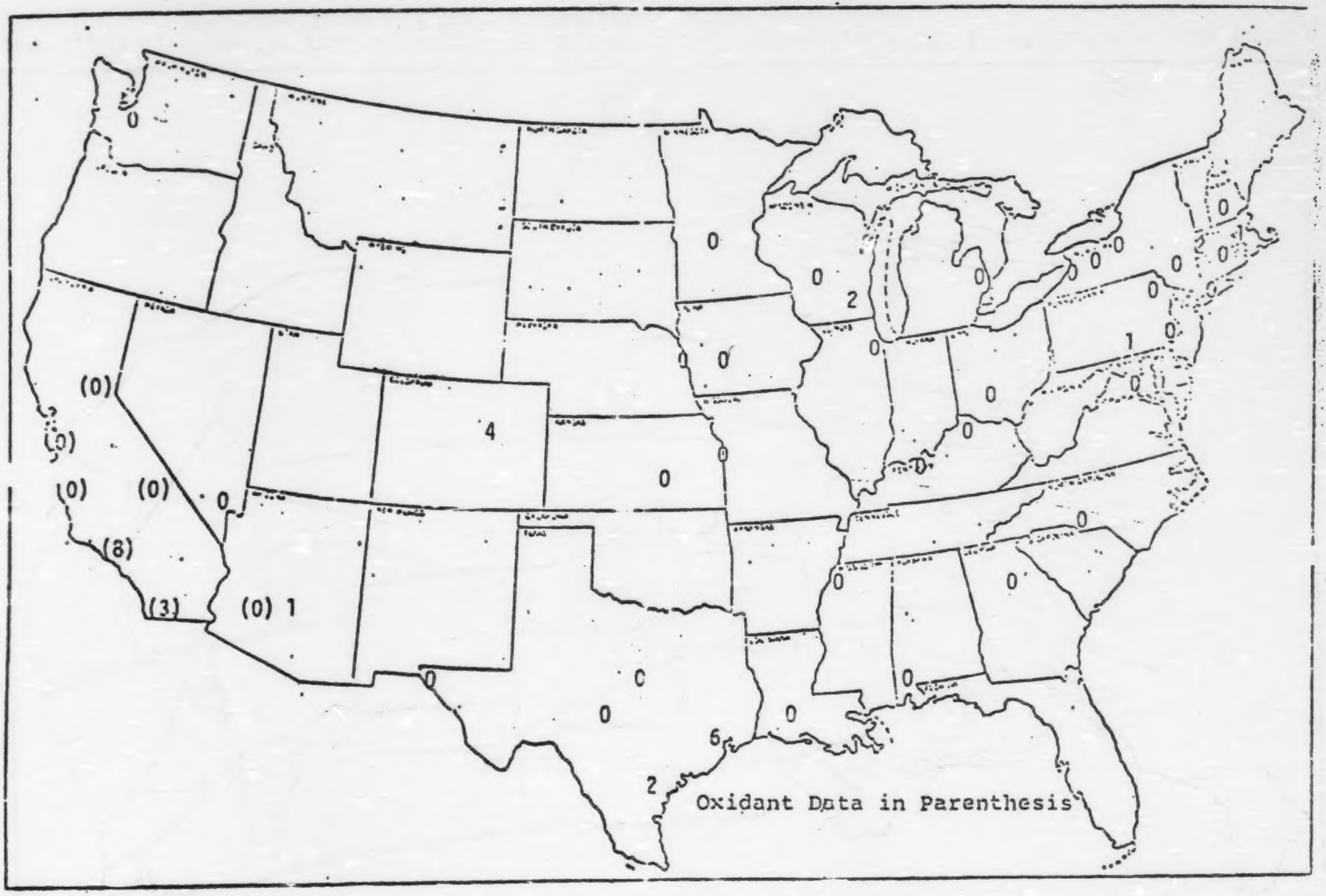
In the current analysis, the frequency of maximum daily temperatures exceeding 59°F at Selected National Weather Service Sites was tabulated for each month over a 5-year climatic period. Assuming that maximum daily temperatures above 59°F indicate high ozone formation potential, the ranges of months that have less than a 5 percent probability of this condition were noted. Since all days with temperatures higher than 59°F will not have all other conditions (solar radiation, air mass characteristics, wind speed, etc.) conducive to formation of high ozone concentration, the 5 percent value represents a reasonably low risk. Accordingly, the geographical areas meeting this criterion for the two sets of cold month ranges December through February and November through March are shown in Figure 1.

Considering the analyses of the two factors, air quality and maximum daily temperature, the areas of the nation with low seasonal incidence of, and low potential for NAAQS violations are well defined. The only possible exceptions are the Milwaukee, Wisconsin area and parts of Massachusetts where oxidant violation frequencies that may be considered appreciable occur despite the temperature data indicating the contrary during colder months. Possible factors that may have caused these anomalies include instrumental error, long range transport, stratospheric intrusions, or some other inexplicable local condition.



NOVEMBER THROUGH MARCH
DECEMBER THROUGH FEBRUARY
TWO MONTHS OR LESS
NO MONTHS

Figure 1. Areas for Which the Probability of Maximum Daily Temperature > 59°F is < 5% During Monthly Ranges Indicated (Based on 5 Years of Temperature Data).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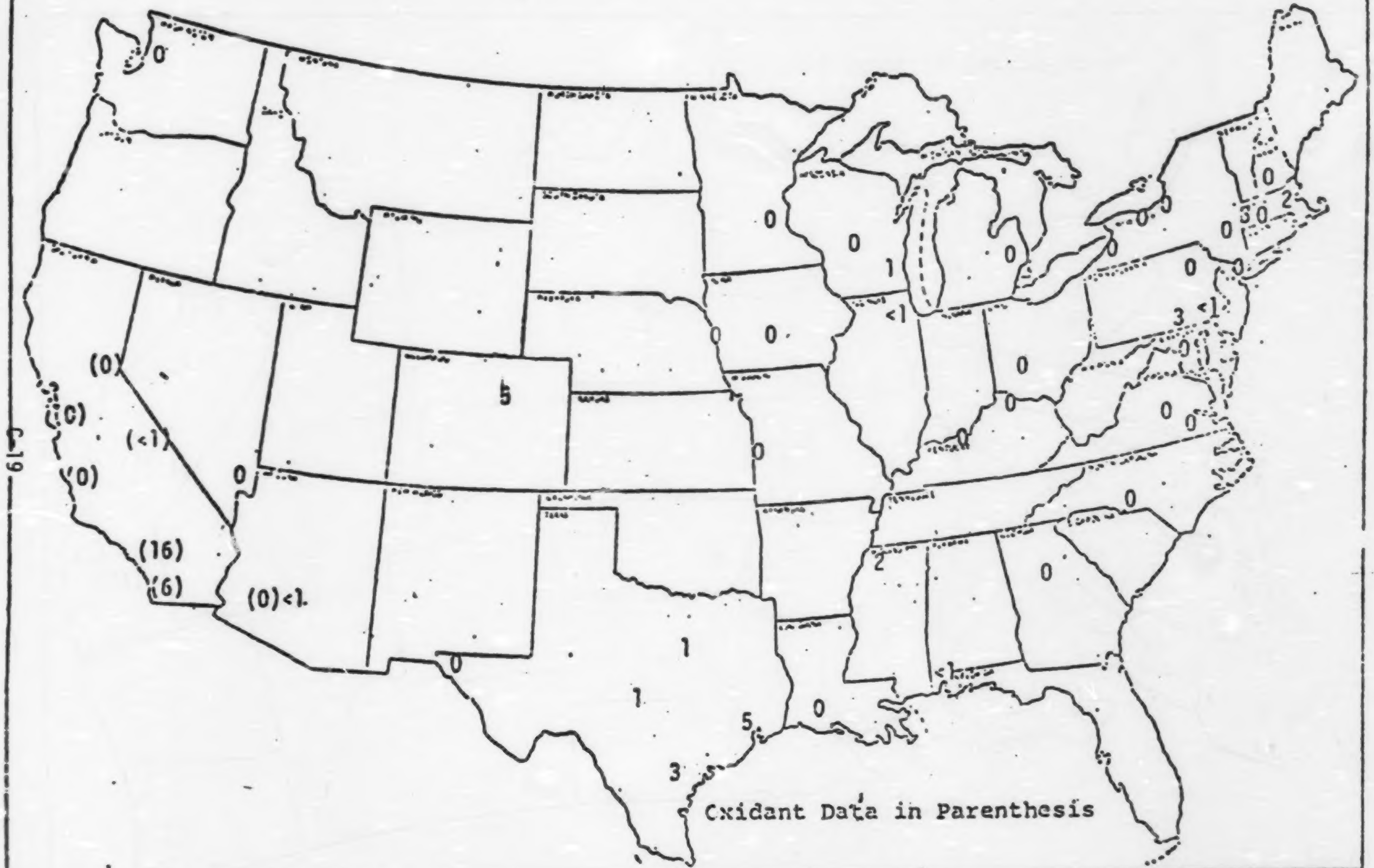
Oxidant Data in Parenthesis

Figure 2. Percent of Days with Maximum Hourly Ozone Concentrations > 160 μg/m³ January, February, and December 1974.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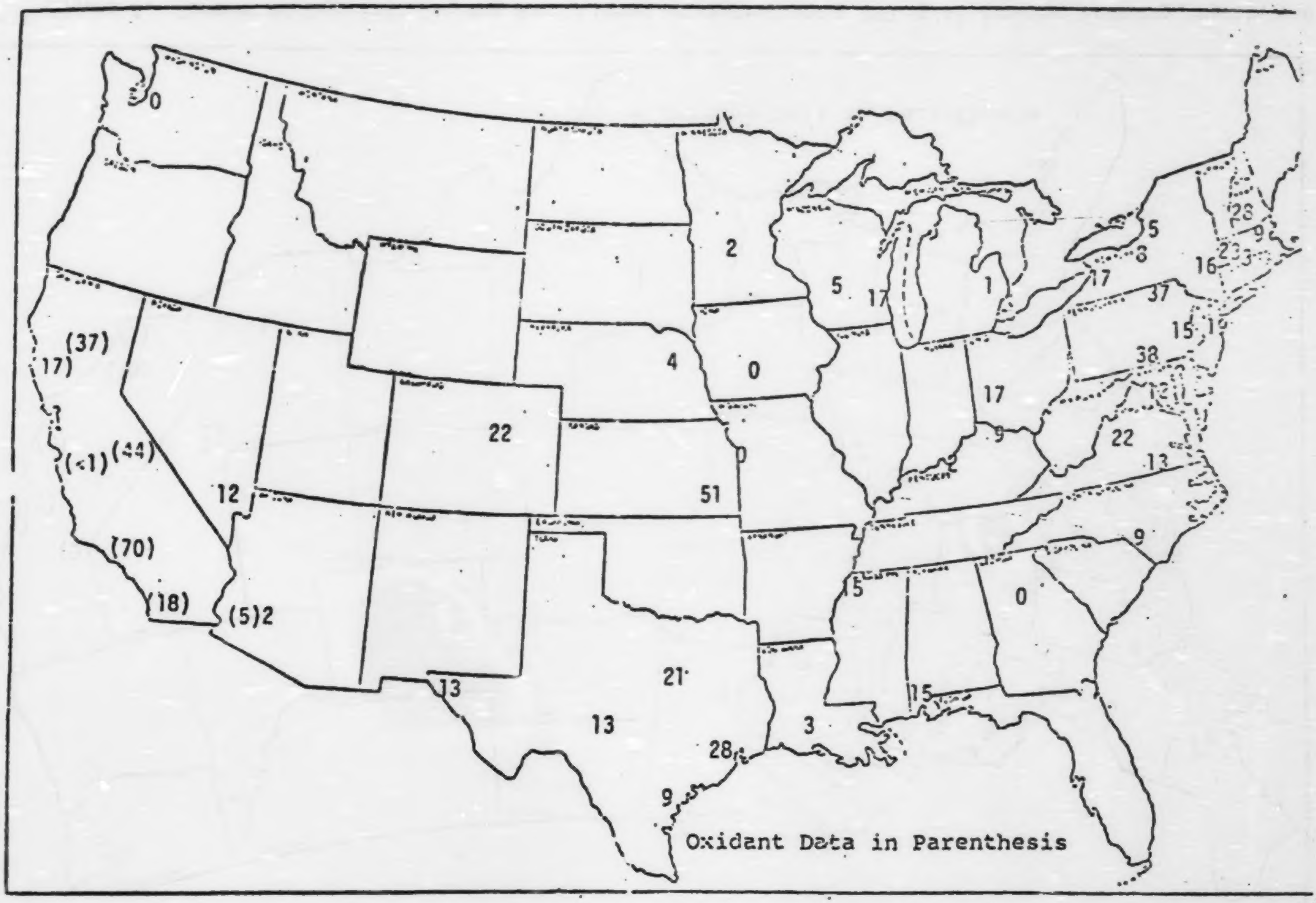
Oxidant Data in Parenthesis

Figure 3. Percent of Days with Maximum Hourly Ozone Concentrations > 160 μg/m³ January, February, March, and November-December 1974.



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9
28
Oxidant Data in Parenthesis

Figure 4. Percent of Days with Maximum Hourly Ozone Concentrations > 160 μg/m³ April through October 1974.

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4. Neligan, R. E., Memorandum to Walsh, R. T., "High Ozone-Oxidant Concentrations and Associated Maximum Daily Temperatures During Cold Season," Environmental Protection Agency, Research Triangle Park, N. C., November 8, 1974

APPENDIX D

APPENDIX D

CONVERSION METHODS

Presented below are techniques which will permit ready conversion between alternative terms which may be used for emission control regulations:

•• English Units - Metric Units

a) Multiply $\frac{\text{Pounds}}{\text{Gallon}}$ by 0.12 to get $\frac{\text{Kilograms}}{\text{Liter}}$

b) Multiply $\frac{\text{Kilograms}}{\text{Liter}}$ by 8.23 to get $\frac{\text{Pounds}}{\text{Gallon}}$

c) $\frac{\text{Gallons}}{\text{Gallon}} = \frac{\text{Liters}}{\text{Liter}}$

•• Water-borne coatings, equivalent organic solvent-borne coatings, volume percent solids, and pounds of solvent per gallon of coating (minus water).

a) From volume percent solids in coating, draw vertical line to appropriate line in Figure D-1 (depending on ratio of water to organic-solvent in coating). From the point of intersection, draw a horizontal line. Where this line intersects the ordinate, read the pounds of solvent per gallon of coating (minus water). Where this line intersects the "Organic-Borne" line, a vertical line yields the solids content of the equivalent organic-borne coating.

b) To convert organic-borne coating to equivalent water-borne, draw a vertical line in Figure D-1 from the volume percent solids to the "Organic-Borne" line. From this intersection, draw a horizontal line.

Where this intersects the appropriate water-borne line, draw a vertical line to yield the solids content of the equivalent water-borne coating. The continuation of the horizontal line yields the pounds of solvent per gallon of coating (minus water) of the organic-borne coating and its equivalent water-borne coating.

** Weight percent solids - Volume percent solids

$$\text{Multiply Weight Percent Solids by } \frac{\text{Density of Coating}}{\text{Density of Solids}} \text{ to get Volume Percent Solids}$$

The density of the solvent may be assumed to be 7.36 pounds per gallon (0.89 kg per liter) unless better information is available. The density of the solids may be calculated from the composition and density of the coating:

$$\text{Density of Solids} = \frac{(100 \times \text{density of coating}) - (\%\ \text{solvent} \times 7.36) - (\%\ \text{water} \times 8.34)}{\text{Percent Solids}}$$

Densities of coating solids may range from 7 to 35 pounds per gallon (0.84 to 4.2 kg per liter).

** Pounds of Solvent per Gallon of Solid - Pounds of Solvent per Pound of Solid

a) $$\text{Divide } \frac{\text{Pounds of Solvent}}{\text{Gallon of Solid}} \text{ by Density of Solid In Pounds Per Gallon to get } \frac{\text{Pounds of Solvent}}{\text{Pounds of Solid}}$$

b) $$\text{Multiply } \frac{\text{Pounds of Solvent}}{\text{Pounds of Solid}} \text{ by Density of Solid In Pounds Per Gallon to get } \frac{\text{Pounds of Solvent}}{\text{Pounds of Solid}}$$

** $$\frac{\text{Pounds of Solvent}}{\text{Gallon of Coating (minus water)}} - \frac{\text{Pounds of Solvent}}{\text{Gallon of Solid}}$$

FIGURE D-1

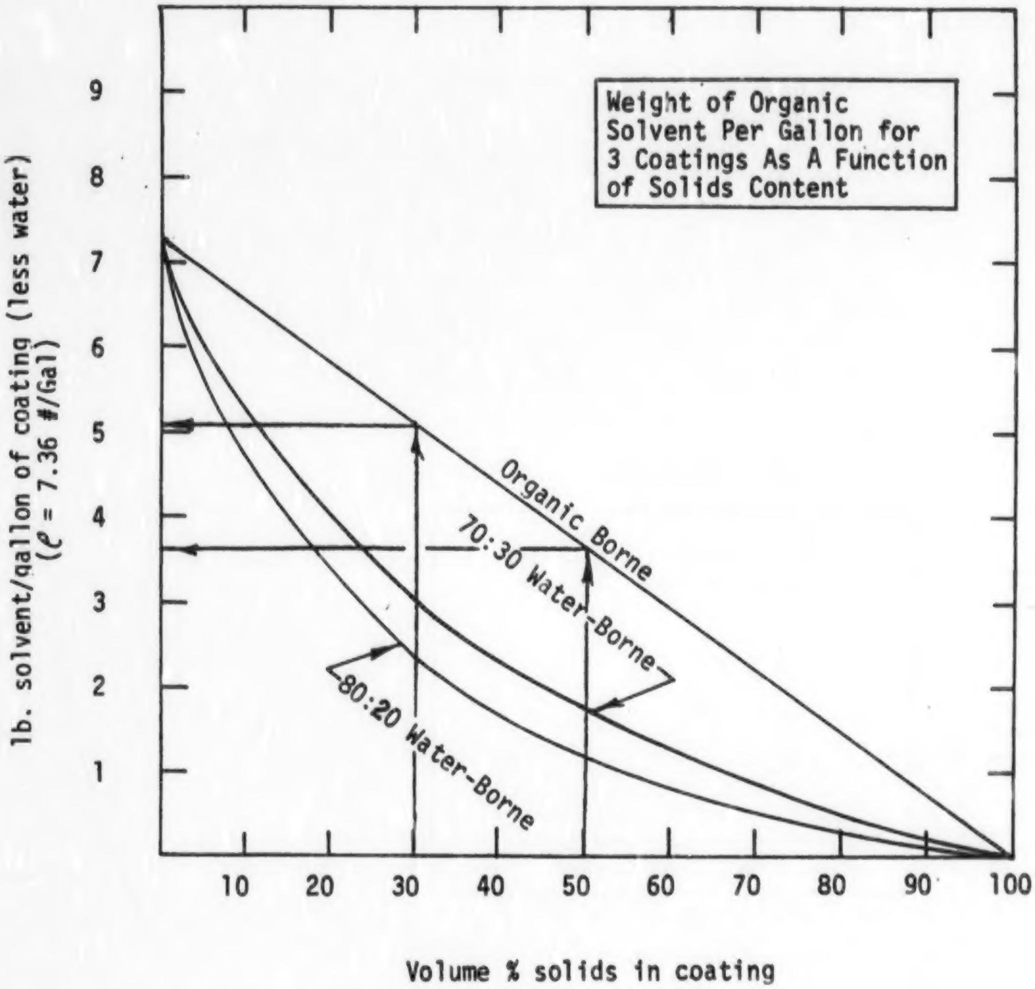

Weight of Organic Solvent Per Gallon for 3 Coatings As A Function of Solids Content
lb. solvent/gallon of coating (less water)
(ρ = 7.36 #/Gal)
9
8
7
6
5
4
3
2
1
10
20
30
40
50
60
70
80
90
100
Volume % solids in coating
Organic Borne
70:30 Water-Borne
80:20 Water-Borne

Figure D-2

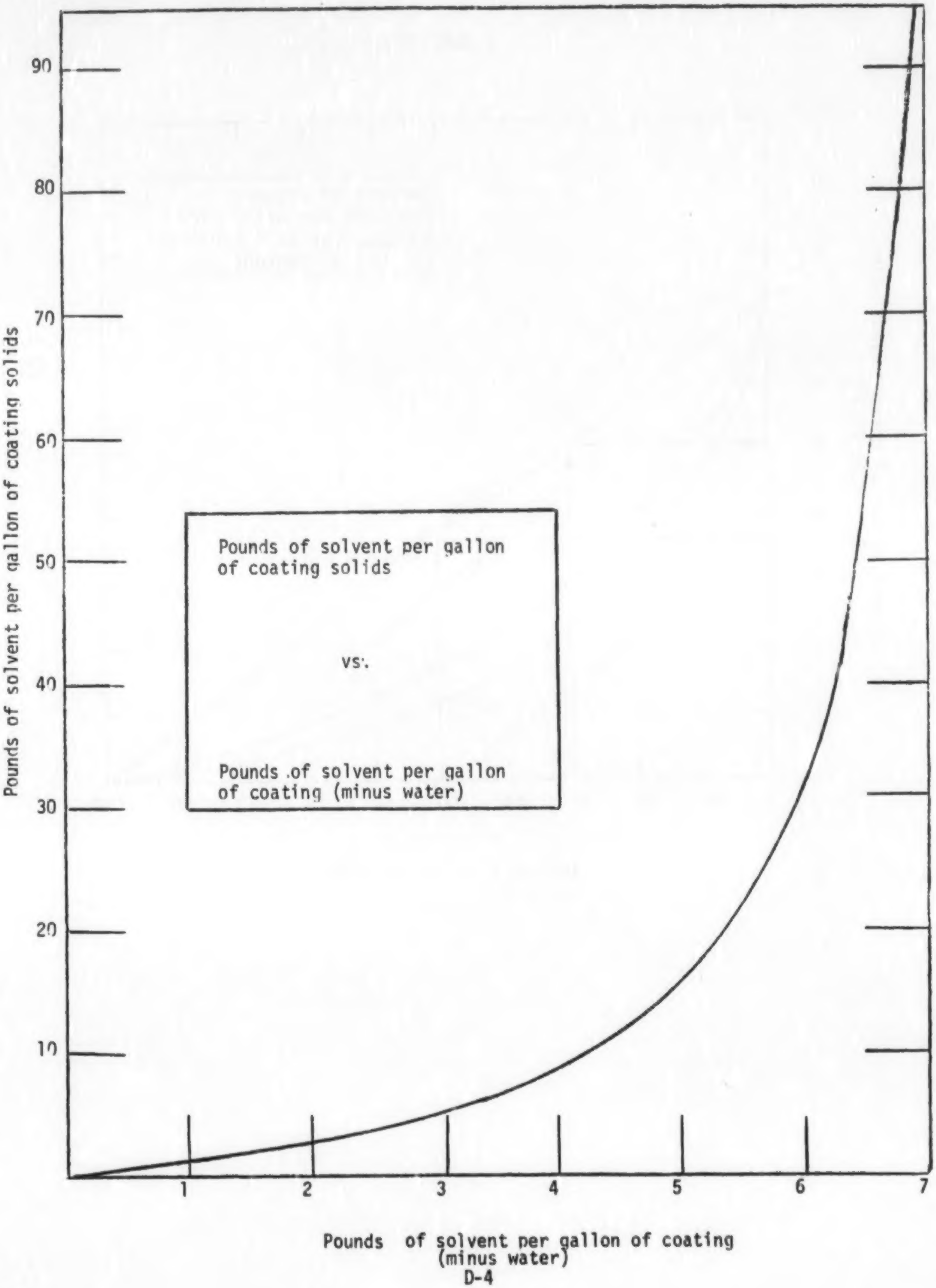
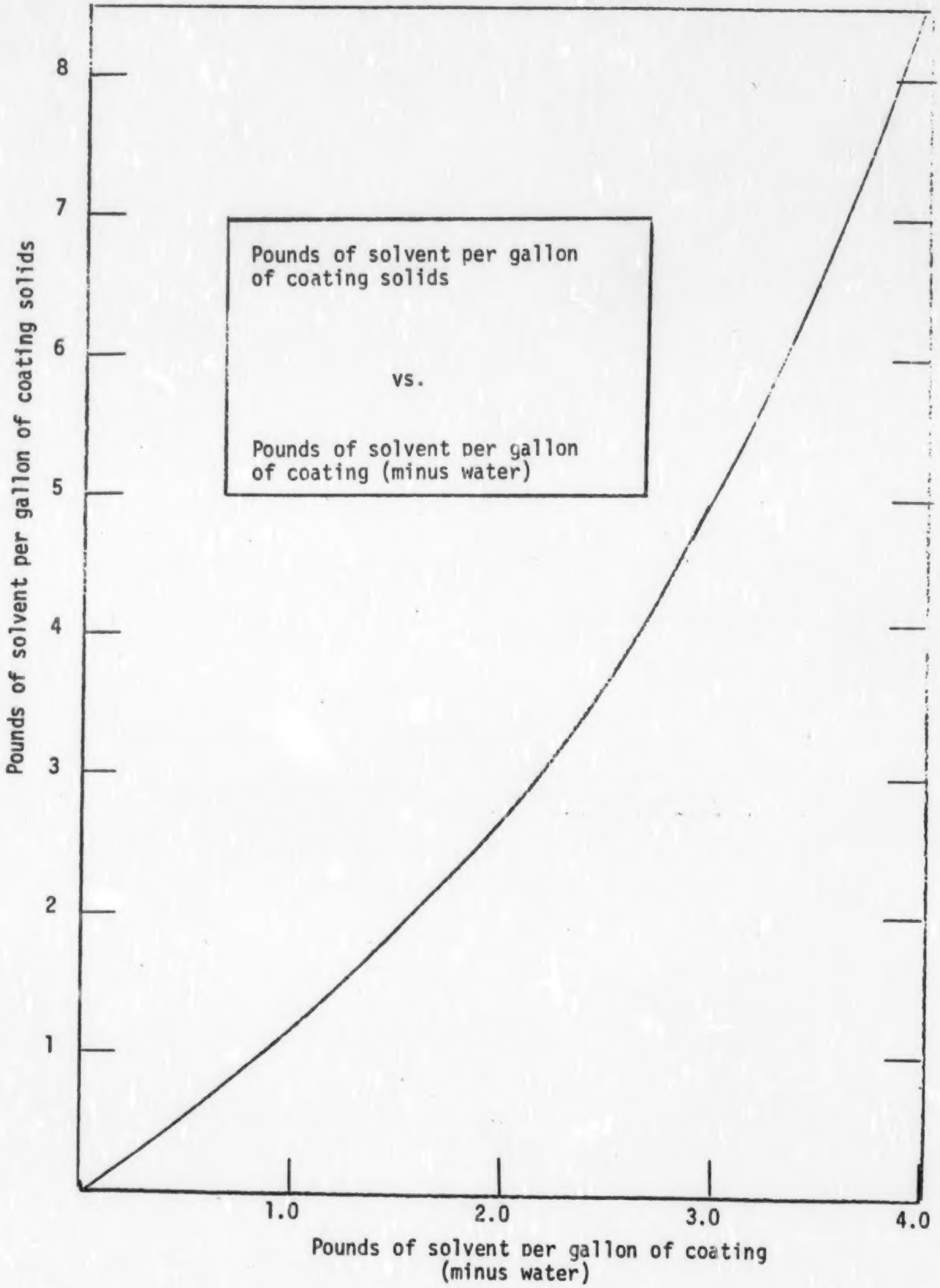

90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7
Pounds of solvent per gallon of coating solids
Pounds of solvent per gallon of coating solids
vs.
Pounds of solvent per gallon of coating (minus water)
Pounds of solvent per gallon of coating (minus water)

Figure D-3


Pounds of solvent per gallon
of coating solids

vs.

Pounds of solvent per gallon
of coating (minus water)
Pounds of solvent per gallon of coating solids
1
2
3
4
5
6
7
8
1.0
2.0
3.0
4.0
Pounds of solvent per gallon of coating
(minus water)